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THE MINERALOGICAL EXAMINATION OF SANDS

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The method of investigation which is to be described in this paper was developed by the writer for the purpose of examining mineralogically, in a rapid and systematic manner, a large number of samples of river and sea sands, or concentrates from such sands, submitted to him by Dr. David T. Day, in connection with the extensive economic study of sands and gravels which is being carried on under Dr. Day's direction by the United States Geological Survey.

In practice, besides purely qualitative results, the method made it possible, when minerals of economic interest were detected, to make a rough estimate of the relative amounts of these, in order to show whether or not the probable value of the sand was sufficient to warrant the making of an exact chemical determination of the one or more valuable elements present. While especial pains were taken to devise a method of procedure the main object of which should be the detection, with as great a degree of certainty as possible, of the significant quantities of minerals having an economic value, the detection of the associated minerals was not neglected, since a full knowledge of these is often of great importance when questions of treatment and extraction arise, to say nothing of the importance of such information from a purely mineralogical or geological point of view.

The economic minerals, whose presence or absence in a sand it is the aim of the following procedure to detect, may be listed as follows:

Magnetite, hematite, limonite.

Psilomelane and other manganese oxides.

Chromite.

Ilmenite, rutile (brookite, octahedrite).

Cassiterite.

Wolframite, hübnerite, scheelite.

Columbite, tantalite, other niobates, tantalites, and titanites.

Uraninite.

Monazite and other related rare-earth minerals.

Abrasive and gem minerals, such as corundum, garnet, diamond.

Gold and platinum metals.

It is, perhaps, almost unnecessary to say here that the detection of small values of gold and platinum metals can only be accomplished by regular assay methods.

A moment's thought regarding the time, labor, and expense involved in making any quantitative chemical estimations of such elements as chromium, titanium, tantalum, tungsten, or the rare-earths will make it evident how very important a reliable preliminary mineral examination is where these rare elements are to be looked for.

While the procedure contains little essentially new to those familiar with modern methods of mineralogical and petrographical investigation, it is believed that this particular application of these methods will be of interest and practical use to those who may have such examinations to make. It is also the writer's hope that it may serve to direct anew the attention of those interested in the mining, testing, or analysis of mineral products, whether sands or not, to the practical value of a careful mineralogical examination by competent parties before launching out into expensive analytical work. The writer could cite very many instances of much time and money wasted for the lack of such simple precautionary measures.

The main lines of attack followed in examining a sample may be briefly summarized as follows:

1. Sizing with screens.
2. Concentration of the heavier minerals with the pan or table, if the sample has not been previously concentrated.
3. Separation into several fractions with the aid of magnets.

4. Examination of these several portions:
   (*a*) with hand lens, noting color, crystalline habit, structure, etc.;
   (*b*) as to streak and hardness;
   (*c*) as to specific gravity of constituents;
   (*d*) as to microscopic characters of the mineral grains;
   (*e*) by means of blowpipe and other chemical tests.

Sizing. — After weighing the sample it is screened through a 24 to 30-mesh (to the inch) sieve. This size mesh yields an undersize well suited for the magnetic treatment, and an oversize which is as fine-grained as can advantageously be examined by the ordinary methods of Determinative Mineralogy. Where sands or gravels which have not been mechanically concentrated and evidently consist largely of quartz, clay, and other light, valueless constituents are to be examined, the sample should, after the removal of the oversize, be panned, jigged, or, better yet, run over a concentrating table, if the latter is available, in order to obtain a sample or samples of smaller size and with a greater concentration of minerals likely to be valuable. If the concentrating table is resorted to it is only necessary to examine the heads and middlings. Many times a rapid inspection of the middlings with a good lens or with the microscope will show that this portion, too, may be discarded. The methods of examination which follow, therefore, apply especially to concentrates from the original sand or gravel. In particular sands, where for any reason especially elaborate magnetic fractioning is desired, the sample is sized through a number of screens of different fineness — the size most suitable in a particular case being determined by experiment, in order to obtain portions in which there will be a fairly uniform size of grain. With the majority of sands the greater part will pass through into the undersize.

Examination of the Oversize. — Aided by the use of a good hand lens, a small magnet, a piece of Arkansas stone (streak stone), a knife, and an occasional blowpipe or simple wet test, one can, with a fairly good knowledge of minerals, determine in most cases, quickly and easily, the minerals present in the oversize and estimate roughly their amount. In the few cases where minerals are found which cannot thus be identified easily, a more elaborate examination must be made, preferably with the aid of Brush and Penfield's determinative tables and some descriptive text. While it is true that any of the minerals possessing chemical and physical properties capable of resisting the natural agents of weathering and disintegration may at times be met with in the oversize, it is also

true that in general only the more common minerals will be found. The mineral character of the oversize is naturally suggestive as to what may be found in the undersize. It is, however, unsafe to rely on such evidence, as the two nearly always differ more or less widely, and are not infrequently radically different.

Examination of the Undersize. Magnetic Treatment. — If the undersize from the sample is a large one, a 25-gram portion is weighed out, care being taken that it is a well-mixed, representative one. If the undersize is small it is taken entire. In either case the portion is next heated in a suitable dish until all hydroscopic moisture is driven off. This prevents the grains from adhering to one another or to the magnets. This sand is then spread out one grain thick on a glass plate, and several fractions are made, consisting of mineral grains of nearly the same magnetic susceptibility, with powerful electro-magnets. It is impossible to get a sharp magnetic fraction, that is, one in which all the grains of the same magnetic susceptibility are picked up at a given distance with a field of given magnetic strength, unless the grains are uniform as to size and shape. Hence when a preliminary examination detects the presence of minerals of interest or points to their probable presence in a sample, it is desirable to screen the sand, as suggested above, so as to get fractions of as uniform a size of grain as possible, and then to make a careful magnetic fractioning of each size, adjusting the strength of the magnet and jumping distance of the grains by experiment until the simplest mineral fractions are obtained. Such a treatment may often result in fractions consisting practically of a single mineral species. It should always be borne in mind in making magnetic fractions that their purity may often be affected seriously by included or adhering grains of a strongly magnetic mineral.

The first fraction is taken out with a large-sized, powerful single-pole electro-magnet fixed at a distance of about 1½ inches above the grains. The strength of the magnet should be so adjusted that it will not pick up crystalline hematite or ilmenite grains except on actually touching them (the writer used grains of crystalline Elba hematite which had been passed through a 24-mesh sieve as a standard). The magnet should be cleaned frequently so as not to allow any considerable thickness of magnetic grains to diminish the jumping distance from the plate. This portion will be called M_1.

The grains remaining on the plate are next passed *slowly* under a powerful two-pole electro-magnet. The distance of the poles above

the grains may conveniently be about 5 to 6 mm., and the current strength regulated so that hematite and ilmenite grains, of size comparable with that of the sand, are easily picked up, but not common red garnet (almandite).

Here especial care should be taken to prevent the accumulation on the magnet of a layer of grains much over a millimeter thick. Except in cases where the amount of material picked up is relatively small, the separation is usually repeated, thus recovering silicates and other minerals carried up by the strong mechanical action of the jumping grains. This portion will be called M_2. Where for any reason considerable quantities of silicates are found in this fraction, they may often be separated readily by a suitable adjustment, determined by experiment, of the jumping distance or the current strength.

The remainder is again passed under the magnet, working at full strength and with the poles barely touching the grains. The portion picked up is again subjected to the same treatment; the product which is still picked up is labeled M_3 and the nonmagnetic portion M_4. Here, again, the fraction may often be divided into smaller and simpler mineral fractions by using different jumping distances or current strengths. For example, in a certain sand examined by the writer the minerals present in M_3 were practically all removed at about 4 mm., a clean garnet fraction made at about 2.5 mm., leaving a residue consisting entirely of a deep amber monazite. The examination of the four magnetic fractions will be discussed in order below.

Magnets. — Any single-pole electro-magnet of fair size, say with a core about an inch in diameter, and of good strength may be used for the first separation. The stronger the magnet the better, since a longer jumping distance may be used with a stronger magnet. The longer the jumping distance the greater, in general, will be the chance for particles, picked up by the rush of magnetic grains, to drop back to the plate. A weak two-pole magnet can, of course, be used here; but the writer has found that with strongly magnetic material like magnetite the relatively straight field of the single-pole magnet gives a fraction cleaner from mechanically included nonmagnetic or feebly magnetic grains than the double-pole field.

For taking out fractions M_2 and M_3 a double-pole electro-magnet capable of giving a very intense, highly concentrated field is required. The distance between the poles must therefore be small and the poles themselves brought to a sharp, wedge-shaped termination.

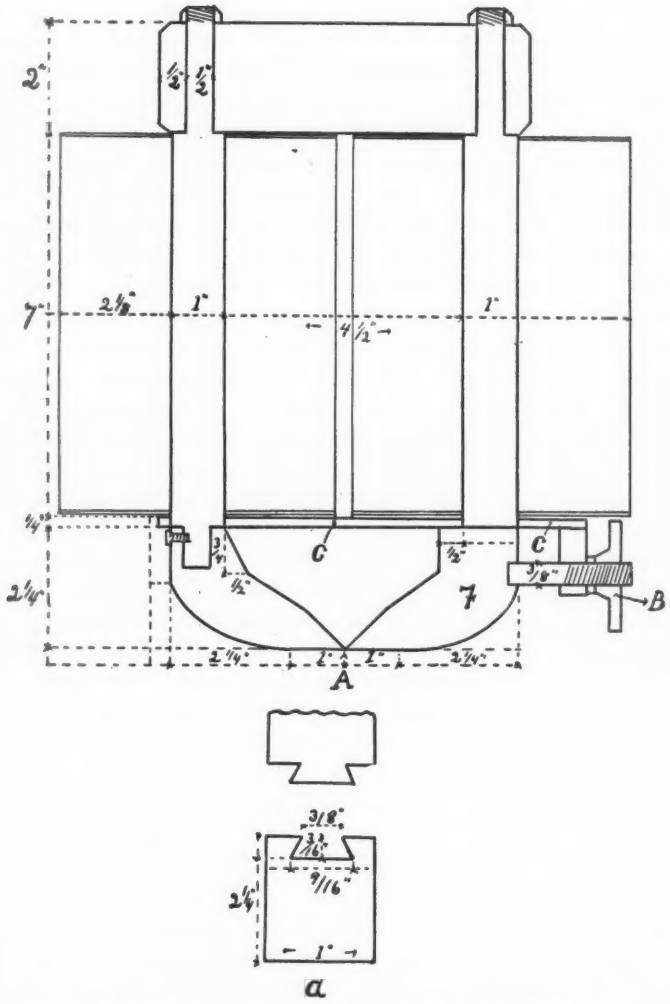

FIG. 1. — FRONT VERTICAL SECTION OF THE MAGNET

A, air space; *B*, brass wheel; *C*, brass bar; *F*, pole piece; *a*, cross section of *F*

For those who may wish to build a magnet for laboratory work, the accompanying diagram and the following brief description of a magnet designed by the writer for use in the mineralogical laboratory

of the Institute may be of value. Figure 1 shows a front vertical section of this magnet. The iron parts are very carefully fitted together so as to do away with any air spaces, and all were thoroughly annealed before finally being put together. The top crossbar is made to extend out over the core pieces on the front and back, as well as on the side (as shown in the plan), so as to ensure the passage of practically all the magnetic flux through the iron. For the same reason the pole pieces are made somewhat heavier than the cores. One of the pole pieces (*F*) is grooved so as to run nicely on a track cut on the end of the core piece. This is shown in side view in Figure 1*a*. Into this pole piece is fastened an iron rod, which is finely threaded for about an inch and made to run through a brass wheel (*B*). This wheel is attached by means of a brass bearing to a brass bar (*C*). The bar (*C*) also serves the purpose of holding the iron cores rigidly in place, and thus prevents a possible movement toward one another when the magnet is working at full strength. By means of the wheel the pole can be moved and the length of the air space (*A*) varied as desired. In practice a gap of about $\frac{3}{16}$ of an inch is generally used. The poles come to a sharp edge 1 inch long.

The winding is on two light brass spools having inside dimensions 7 inches long by $2\frac{1}{8}$ inches deep. These allow for, approximately, 4,000 feet each of No. 18, double cotton-covered, copper wire. As a matter of precaution the coils are separated from the spools by two layers of paper. The magnet is run directly on a 110-volt current for its full strength, which, of course, can be cut down by the introduction into the circuit of suitable resistance. By using poles which are terminated with truncated cones, whose sides have a slope of 40 or 60°, either a field of uniform or maximum intensity, respectively, can be obtained, and the magnet becomes useful for demonstrating the magnetic properties of crystals or of crystal sections.

Strongly Magnetic Portion. M_1. — The portion taken out by the first treatment consists, in general, largely or entirely of magnetite. In some sands, where ilmenite and hematite and limonite adhere to or are intergrown with the magnetite, very considerable portions of these minerals will be found in M_1; and in any case, if these minerals are abundant in the sand, a variable amount will always be swept up by the rush of magnetite particles. The ilmenite, etc., while not actually picked up if alone, are strongly affected by the magnetic flux, and are thus virtually rendered lighter, so that the "sweeping up" takes place

all the more easily. Small amounts of other unimportant minerals may adhere to the magnetite or be carried up mechanically, but in general the fraction represents roughly the amount of magnetite present in the sand. If present, meteoric or terrestrial iron and the nickel iron alloys, awaruite and josephenite, would be found in M_1. The writer has never observed these latter in the undersize, and unless present in considerable amounts they would be difficult to detect where the undersize was fine. Where the grain was coarser they could probably be recognized by their steel-like surface and their toughness under the hammer or pestle. If desired, the magnetite portion may be tested chemically for titanium as described beyond.

Magnetic Fraction. M_2. — The minerals most commonly met with in this portion are ilmenite, hematite, chromite, limonite; less commonly, hypersthene, garnet, hornblende, pyroxenes (often here because of abundant inclusions of magnetite), iron-rich epidotes; rarely, rutile altered on the surface to ilmenite, wolframite, columbite-tantalite, samarskite, or related minerals. It is true that many other minerals of little or no commercial value might be found here in small quantities, calling for an amount of labor to identify them, if indeed they could be identified at all, out of all proportion to the importance of the mere fact of their being present in this fraction.

A careful examination of the fraction with a powerful lens should be made first. The important characteristics which may be noted are tabulated below, together with the names of the corresponding minerals. It may be remarked here that even with a comparatively short experience in examining these sands the eye becomes very expert in detecting distinctions of color and lustre too fine to be described.

Name of Species	More Important Characteristics
Ilmenite.	Black, shiny, crystalline plates, often with hexagonal outline; edges frequently highly modified; bases commonly pitted. Also crystals of pseudo-octahedral habit, due to nearly equal development of the rhombohedral $(10\bar{1}1)$ faces and the base (0001). Flat plates with rounded (worn) edges. Commonly as iron-black, rounded, irregular grains.
Hematite (Turgite).	Occasionally as iron-black or gray, shiny, hexagonal, tabular, and pseudo-octahedral crystals, similar to ilmenite. Sometimes as black or reddish black octahedral crystals after magnetite (martite); also cubical and pyritohedral after pyrite. Thin plates and scales; gray by reflected,

Name of Species	More Important Characteristics
Hematite (Turgite).	opaque or dark red by transmitted light. Commonly in rounded, irregular grains, sometimes fibrous in structure, black or reddish in color. (The massive and fibrous forms are often turgite.)
Limonite (Goethite).	Limonite as black to brownish black cubes, octahedrons, pyritohedrons, pseudomorphic after pyrite. Commonly (also goethite) in prismatic, radiated, irregular, rounded grains; often fibrous.
Chromite.	Black (usually pitch black) octahedrons, more or less rounded, often nearly spherical grains, showing a shiny black conchoidal fracture.
Wolframite.	Black or brownish black rounded grains, showing, where broken, a good cleavage in one direction.
Samarskite, or related minerals.	Black or brownish black grains with a resinous or pitchy lustre. Show a pronounced conchoidal fracture.
Columbite-tantalite.	Black or bluish black grains; nothing particularly characteristic.
Garnet.	Dodecahedral and trapezohedral crystals more or less rounded, the smaller crystals being usually quite perfect. Color, various shades of red, also blackish and brown.
Hypersthene.	Greenish brown, square, elongated prisms, with the ends usually rounded. The prisms and ends are sometimes truncated by small faces. Less commonly as rounded grains.
Hornblende.	Black, lustrous, prismatic, angular grains, frequently exhibiting the two excellent prismatic cleavages of hornblende; also as dull, rounded grains.
Pyroxene (Augite).	Usually as brownish or greenish black, rounded grains, sometimes showing a square prismatic form.
Tourmaline.	Black, irregular, rounded grains, sometimes prismatic; striated longitudinally; vitreous lustre.
Serpentine.	Light to dark green; also yellowish, round, opaque, or semitransparent grains, with inclusions of iron ores.

There are no other minerals likely to occur in this fraction which could be recognized at sight by any characteristic appearance under the hand lens. The microscopic characteristics of the minerals occurring here which transmit light are the same as those described under M_3, and will be taken up there.

A further study of this portion may be made as follows: about one-half a gram of the well-mixed portion is reduced to a *very fine* powder.

Streak. — The color of the powder (streak) should be noted, as it may throw light on the composition of the sample. Some of the powder should be rubbed out very thin on paper, so as to get the color of the finest dust. This is important, as many powders appearing almost black will show a very noticeable and often characteristic color if rubbed on the paper.

In a general way:

a red streak points to ferric oxide, hematite, or turgite;

a dark reddish brown streak *may* indicate wolframite or columbite;

an ochre brown streak indicates limonite;

a pure brown streak indicates chromite;

a black streak indicates ilmenite;

a light-colored streak — red, brown, or gray — points to the presence of silicates.

Chromium. — About 0.2 mg. of the powder is introduced into a borax bead (3 mm. diameter) on a loop of platinum wire, and heated in a strong reducing flame before the blowpipe. A characteristic emerald-green bead (when cold) is obtained (best seen against a white background) if chromium is present in the fraction. Actual tests made by the writer on carefully prepared and weighed mixtures of the minerals coming in this magnetic fraction of the sands have shown that this test is not obscured by any of the elements present in the minerals. To the practiced eye the test is reliable if 1 per cent. of chromium is present in the fraction, and of course this represents a much smaller percentage in the sand. To any one not thoroughly familiar with the particular shade of green given by chromium, it is important to have two borax beads, one with a very small amount of some chromium salt and the other with about 0.2 mg. of ilmenite dissolved in it, for comparison.

Titanium and Tungsten. — From 0.2 to 0.3 gram of the powder is next mixed with five or six volumes of soda and fused thoroughly on a piece of charcoal before the blowpipe. (In rare instances a faint coating of oxide of tin may be obtained on the coal. The tin may come from varieties of columbite, wolframite, or even from cassiterite mechanically carried up, or where the latter is intimately intergrown with oxide of iron.) The fusion is cut from the coal, powdered in a

mortar, and boiled in a test tube thoroughly with four successive 10 c.c. portions of water, the liquid being decanted through a filter so as not to disturb the residue. The filtrates from the first two leachings are caught in a test tube, acidified, and boiled with hydrochloric acid. If tungsten is present to the extent of about one-half of 1 per cent. an opalescence will appear in the solution; and if a piece of tin is added and the solution boiled for three or four minutes a characteristic blue coloration appears, and eventually a small deep blue precipitate settles to the bottom of the tube. If tungsten is present in large quantity a thick, white cloud separates on acidifying, which readily changes on boiling into the yellow tungstic acid, and this becomes deep blue when reduced with tin.

The residue insoluble in water is now boiled thoroughly with hydrochloric acid, poured through a filter to remove charcoal and any undecomposed mineral, and boiled down with metallic tin. If titanium is present in amount exceeding about 3 per cent. a distinct violet color will be obtained. If no color is obtained, and it is important to know the titanium content, the amount may be estimated colorimetrically by the well-known hydrogen peroxide method. Some titanium is almost invariably present.

Tantalum. — Unless fragments of minerals carrying tantalum are found in the oversize, when there is no difficulty in identifying them, there is very little chance of their being recognized or their presence proved in the undersize unless very considerable amounts are present. The characteristic pitchy lustre of samarskite, exuenite, and other similar minerals may be recognized when the grains are fairly abundant if the erosion undergone by the grains has not destroyed their lustre.

So far as the writer is aware, there is no quick or simple test for small quantities of tantalum in the presence of titanium. The element niobium, which usually accompanies tantalum, can be detected with less difficulty; but if tantalum and niobium are present in an amount less than about 5 per cent. they cannot be detected with certainty without an elaborate qualitative test, such as is recommended by Professor A. A. Noyes.[1]

Where niobium is present in as large amounts as 10 per cent. and tungsten is absent, or removed by fusion with soda and leaching, a very

[1] Technology Quarterly, XVII, No. 3, September, 1904.

satisfactory test for niobium may be made as follows:[1] About 0.1 gram of mineral is fused with three or four volumes of borax, the fusion dissolved in hydrochloric acid and reduced with a piece of granulated tin. The violet of titanium appears first, but later takes on a bluish shade and becomes quite blue on longer boiling. With smaller amounts than 10 per cent. present, the writer has not been able to get satisfactory results.

Magnetic Fraction. M_3. — In this fraction we may find any of the minerals mentioned under M_2. Where care has been taken in making the magnetic separation, this fraction will usually contain relatively little hematite, ilmenite, or iron-rich chromite. Slight variation in the chemical composition, in the size of the grains, in the way they lie (on edge or face) doubtless accounts for the distribution of essentially the same mineral species through both of these magnetic fractions. The proportion of the silicates in M_3 to the metallic minerals is, however, in general much greater than in M_2. The less strongly magnetic varieties of the metallic oxide minerals and of columbite-tantalite and wolframite are also more abundant here. Uraninite may be found here if the magnetic pole touches the grains. The deeper colored varieties of monazite may also be found in M_3, sometimes quite abundantly. Grains of quartz and other nonmagnetic minerals which have become covered or filled with iron rust are also very commonly picked up at this point.

As suggested earlier, both M_2 and M_3 may in special cases be subjected to a much more elaborate magnetic fractioning, in which case the microscopic and other tests are often much simplified.

The remarks regarding the habit of the metallic mineral grains and the streak given under M_2 apply to this fraction as well. The same chemical and blowpipe tests are also applicable, with an additional test for monazite, where the mineral appears to be present, as described beyond under M_4, and an acid test for gelatinous silica (chrysolite), where this mineral is also thought to be present. For this latter test ½ gram of the fraction, very finely ground, is boiled with dilute nitric acid, filtered, and the filtrate evaporated. If chrysolite is present gelatinous silica will separate out.

The silicates can often be satisfactorily identified by simple inspection with a lens. Further study of them may be made with the

[1] Brush and Penfield: Determinative Mineralogy.

polarizing microscope. For such examination a small portion of the fraction (0.1 to 0.2 of a gram) is placed on a glass slide and the grains covered with a drop or two of some colorless oil, so as to imbed them in a medium of higher refractive index than air (cedar oil is excellent) ($n = 1.52$). One who has not had experience with the optical properties of silicate grains of varying size under the microscope should prepare sample slides for comparison by crushing up typical specimens of the common rock-forming silicates, sizing the grains to make them comparable with sand grains. It must be borne in mind by one used to studying minerals in thin rock sections, where a uniform thickness is usually obtained, that in a sand where the grains may differ considerably in thickness wide variations in depth of color, absorption, pleochroism, and interference colors may occur between grains of the same material. Since the grains usually exceed in thickness the minerals in a good thin section, the phenomena just mentioned will, in general, appear more marked than in thin section. In the table below are given the main characteristics most useful in readily identifying the common silicates met with in this fraction. For further details a text-book on mineralogy may be consulted.

Mineral	With Hand Lens	Appearance under Microscope
Garnet (of varying composition, but consisting chiefly of the almandite molecule).	Red and pink of various shades. When altered, brownish; rarely yellowish brown or nearly black (altered). Occurs as irregular grains, but more commonly in round grains with dodecahedral and trapezohedral outlines, also frequently as perfect crystals.	In plane polarized light, light pink to almost colorless, clear grains or crystals. Between crossed nicols, usually isotropic, occasionally anomalous.
Epidote (iron-rich variety).	Yellowish green (pistachio). Less common as brownish green and greenish black grains. These are commonly rounded. Often in prismatic forms with rounded ends; fre-	Often shows distinct parallel cleavage lines. In plane polarized light shows distinct and characteristic pleochroism in light shades of yellow, yellowish green, and yellowish brown; rarely reddish. Between crossed nicols shows very strong bire-

Mineral	With Hand Lens	Appearance under Microscope
Epidote (iron-rich variety).	quently shows one perfect cleavage.	fringence. Interference colors white, of higher order where grains are over 0.06 mm. thick.
Hornblende.	Black to greenish black or green grains, often prismatic, and showing lustrous, perfect prismatic cleavages.	In plane polarized light shows marked pleochroism and more or less absorption in shades of green, bluish green, yellowish green, to yellow; rarely brown. Between crossed nicols rather high interference tints, often somewhat hidden by the natural color; extinction at angles of from 0–15° with the cleavage lines, which are usually well marked.
Hypersthene.	Usually square prismatic crystals, sometimes with terminal faces, more often rounded ends. Sometimes as rounded grains. Color, dark brownish green.	In plane polarized light pleochroism marked to strong, parallel to C = c′ = elongation of crystal, green. Parallel to A = a, reddish brown or yellow. Parallel extinction with crossed nicols; low interference tints. Crystals often carry abundant inclusions of magnetite or ilmenite.
Bronzite Enstatite.	Prismatic grains of a light grayish green to olive-green color. Bronzite sometimes shows a bronzy lustre.	Little if any pleochroism; parallel extinction; low double refraction; C = c′ = elongation.
Pyroxene (Diopside, Augite).	Usually dull, vitreous, green, also brownish to black grains, rarely showing any distinct crystalline form.	Color, usually light green. In plane polarized light little or no pleochroism, except in violet-brown colored grains, where it is distinct. With crossed nicols, high interference colors; extinction angle usually large.
Chrysolite (Olivine).	Light green, rounded grains (gelatinous silica test serves to detect this mineral when its presence is suspected).	No pleochroism nor distinct cleavage. Very high interference tints. Extinction usually parallel to crystallographic outlines if these are present.

Mineral	With Hand Lens	Appearance under Microscope
Serpentine.	Light yellow or greenish to dark green, round grains; dull lustre; often with black iron ore inclusions.	Non to semitransparent grains, as described opposite.
Tourmaline.	Black, prismatic, or round grains, vitreous lustre.	Strong absorption and pleochroism, perpendicular to the vertical axis. The prismatic grains give parallel extinction between crossed nicols.
Biotite and phlogopite.	Brown to black plates and scales.	Light to dark brown plates, easily recognized by appearance.
Chlorite.	Green plates and scales.	Green flakes; very low interference colors.
Monazite (probably, also, some varieties of xenotime and related minerals).	Commonly occurs as equidimensional grains retaining some crystallographic boundaries. Possesses a characteristic amber color, often with a brownish or reddish tinge.	Crystalline boundaries often distinct; also good basal cleavage, and sometimes other cleavages or partings. A rich, characteristic yellow or orange-yellow; sometimes reddish or brownish color. Slight pleochroism or absorption. High interference tints between crossed nicols. Extinction nearly or quite parallel to crystal outlines and cleavage.
Allanite (rare)	Brown to black grains.	Red pleochroic grains.
Staurolite (rare).	Brown, sometimes with crystallographic outlines.	Orange to brown pleochroic grains.
Cordierite (Iolite).	Prismatic, rounded grains of bluish color.	Striking pleochroism in shades of blue or violet to yellowish white. Absorption also marked, perpendicular to elongation of prism; parallel extinction. Often shows alteration.
Quartz (Chalcedony, Flint, Jasper, etc.), Feldspar.	Brown, reddish to red (with iron rust), irregular grains.	Often show a white matrix filled with rusty materials, commonly amorphous in appearance.
Rock grains.	Round grains of various dark-colored, compact rocks.	

Nonmagnetic Fraction. M_4. — The more important minerals which may be met with in this fraction are as follows, the most common ones being italicized:

Mineral.	Specific gravity.	Mineral.	Specific gravity.
Quartz (*chalcedony*, flint, jasper, etc.)	2.6 –2.66	Spinel	3.5 –4.4
Feldspar	2.57–2.75	Titanite	3.4 –3.56
Serpentine	2.50–2.65	Diamond	3.51–3.52
Cordierite	2.60–2.66	Corundum	3.95–4.10
Beryl	2.65–2.80	*Rutile*	4.18–4.25
Muscovite	2.76–3.0	(Brookite, octahedrite)	(3.8 –4.01)
Actinolite and *tremolite*	2.9 –3.2	Xenotime	4.45–4.56
Diopside	3.2 –3.38	*Monazite*	4.9 –5.3
Tourmaline	3.0 –3.1	*Zircon*	4.68–4.7
Epidote (zoisite)	3.25–3.38	Thorite	5.19–5.4
Andalusite	3.16–3.26	*Cassiterite*	6.8 –7.1
Sillimanite	3.23–3.24	Thorianite	9.0
Cyanite	3.56–3.67	Other rare-earth minerals ranging from	4.0 –6.0
Apatite	3.17–3.23	Pyrite	4.95–5.1
Topaz	3.4 –3.6	Chalcopyrite	5.7
Garnet (light)	3.4 –3.6	*Light-colored rock grains*	2.6 –3.05

Very often careful inspection with the hand lens will be sufficient to show that this fraction contains no minerals of any technical importance, in which case nothing further need be done with it. In cases of doubt, or where there appears to be some valuable mineral present, a microscopic examination may be made. The writer, however, has found it better, in general, to defer the microscopic examination until the portion has been further fractioned by the use of heavy solutions. An examination of the specific gravities of the minerals listed above will show that quartz (chalcedony, flint, etc.), feldspar, serpentine, beryl, and some varieties of tremolite, diopside, tourmaline, and apatite, are under 3.18. These may therefore be floated in a Thoulet solution (potassium mercuric iodide, density 3.18), and thus separated easily from the others. To accomplish this separation M_4, or a suitable weighed portion of it, is poured slowly, with gentle shaking, into about 10 to 15 c.c. of the Thoulet solution, held in a separatory funnel of about 50 c.c. capacity. The part of the funnel holding the liquid may conveniently have a length of 12 cm., a maximum diameter of

3 to 3.5 cm., tapering downward to a minimum of 1.2 cm. It should have an outlet through the ground glass cock of about 3 mm. After standing until the heavy minerals have all settled they are drawn off, washed thoroughly with water on a filter, dried (weighed, if desired), and a portion imbedded in a drop of oil and examined under the microscope. The portion which floats consists almost always of silica and feldspar or siliceous rock grains, and is of little interest except as regards its relative amount. It would be an unnecessary repetition to give here the microscopic or megascopic characters of all the minerals of this fraction, as most of them are either familiar to all mineralogists or can be readily found in a text-book. A few of the more striking characters, however, which are useful in recognizing at sight the important minerals of the heavy portion, are given in the following table:

Mineral	With Hand Lens	Characteristic under Microscope
Monazite.	Characteristic equidimensional amber-colored grains, often with a brownish or reddish tinge. Crystalline habit well shown.	Color, a clear yellow or amber. Crystalline boundaries often good; basal cleavage good; other cleavages or partings sometimes present. Little if any pleochroism or absorption. High interference colors; extinction nearly or quite parallel to crystal outlines and basal cleavage.
Epidote (can be separated from monazite with barium mercuric iodide solution, sp. gr. 3.55).	Pale yellow to yellowish green grains, usually rounded, sometimes prismatic.	Often shows distinct cleavage lines. In plane polarized light shows distinct and characteristic pleochroism in light shades of yellow, yellowish green, and yellowish brown. Rarely reddish. Between crossed nicols shows very strong birefringence. Interference colors white, of higher order where grains are over 0.06 mm. thick.
Zircon.	Usually as small, highly lustrous, colorless, more rarely red, amethystine or smoky crystals, of square, prismatic habit, often	See opposite. Parallel extinction. Very high double refraction. Interference colors white, of higher order, except in very small crystals. Crystals show very marked dark total reflec-

Mineral	With Hand Lens	Characteristic under Microscope
Zircon.	doubly terminated. The crystal ends are commonly somewhat rounded, but are frequently very perfect. This last is especially true of the smaller sized crystals. Rarely in round grains.	tion borders, due to the strong single refraction.
Titanite.	Colorless, light yellow, brown grains, often with characteristic acute crystal habit.	See opposite. Interference colors as high as zircon; darker colored varieties show pleochroism. High single refraction, with strong total reflection border.
Garnet.	Colorless to pale pink, rarely greenish, rounded crystalline grains. Isometric habit.	See opposite. Isotropic.
Cyanite.	Colorless to light blue or green prismatic crystals.	Colorless or light blue or green (particularly in parts of the crystal). Single and double refraction high. Perfect cleavage parallel to prismatic elongation. Often shows parting perpendicular to this. Extinction oblique to cleavage.
Sillimanite.	Colorless, prismatic, often fibrated crystals.	Colorless, often fibrous crystals; cleavage appears as very fine cracks parallel to elongation; a transverse parting is often seen. Extinction parallel to cleavage ($c' = C$); strong single and double refraction.
Andalusite.	Prismatic, colorless to reddish crystals, rarely transparent.	Crystals are usually filled with inclusions of other minerals, carbonaceous matter, etc. Extinction parallel to the prismatic elongation [$(c = A)$ distinction from sillimanite]. Single refraction high, double refraction rather low. Pleochroism if present is reddish parallel to elongation, green to colorless perpendicular to it.

Mineral	With Hand Lens	Characteristic under Microscope
Rutile (Brookite, Octahedrite).	Red or yellowish brown to nearly black crystalline grains. Rutile prismatic, striated, twinned. The crystalline peculiarities of the three serve to distinguish them.	Deep red by transmitted light. Very high double refraction. Rarely opaque. The striations and twinning of rutile are characteristic.
Cassiterite.	Rounded, opaque, brown or reddish brown grains, often with concentric structure, also lustrous brown, reddish yellowish to nearly colorless crystals.	Commonly opaque. Crystals show high double refraction and relief; colors as noted opposite.
Uraninite (Pitchblende).	Black, pitchy, rounded grains.	Opaque.
Thorianite.	Black cubical crystals.	Translucent, with reddish color, when small or when broken into thin fragments.
Other "earth" minerals of uncertain identity.	Brown, pitchy, or resinous lustre; grains, sometimes with crystalline outlines.	
		Physical Characters
Gold.	Yellow flakes; sometimes show traces of crystalline structure.	Malleable.
Platinum and Paladium.	Whitish steel-gray flakes or nuggets.	Malleable. Hardness 4–4.5.
Iridium.	Silver-white, tinge of yellow.	Less malleable than platinum. Hardness 6–7.
Iridosmine.	Tin to silver-white, steel-gray.	Slightly malleable. Brittle. Hardness 6–7.
Sperrylite.	Tin-white, octahedral or cubical crystals, often showing pyritohedral modifications.	Hardness 5–6. Brittle. Reacts for arsenic when heated in open glass tube; the residue reacts for platinum.
Laurite.	Metallic, iron-black, octahedral crystals or rounded grains.	Heated in the open glass tube, reacts for sulphur, and gives on further heating fumes of osmic oxide.

Mineral	With Hand Lens	Physical Characters
Pyrite.	Light brass-yellow isometric crystals or broken fragments.	Hardness 5.5. Brittle, conchoidal fracture.
Chalcopyrite.	Brass-yellow fragments.	Hardness 3.4. Brittle.
Arsenopyrite and related Arsenides.	Steel-gray to silver-white crystals of isometric or orthorhombic habit, or fragments.	React for arsenic or sulphur or both, and become magnetic on heating before the blowpipe.
Cinnabar.	Bright red, opaque, irregular rounded grains.	Soft; easily volatile when heated in a closed glass tube, yielding a black sublimate which turns red if rubbed on paper.

There is usually no doubt after the microscopic examination as to the presence or absence of monazite. If there is any uncertainty in this regard, or if grains are present which cannot be readily identified, the chemical tests given below are useful. They serve to detect the presence, not only of monazite, but of other rare-earth minerals, and of tungsten and tin.

Monazite, Rare-Earths, Tungstates. — 0.10 to 0.15 gram of the finely powdered grains are moistened in a test tube with three to five drops of sulphuric acid, and heated until the acid has fumed for a minute or two. The tube is then cooled, diluted with 10 c.c. of water, allowed to settle after a good shaking, and the solution decanted through a filter. If monazite, xenotime, or other minerals carrying the rare-earths and decomposable by the acid (and the majority of such minerals are) are present, a white or pinkish precipitate of earth oxalates will be thrown down when 10 c.c. of a saturated solution of oxalic acid is added. The solution should be allowed to stand if small quantities are to be detected. Ammonium oxalate may be used here, but where apatite, calcium phosphate, is present in the fraction, as it often is, there is danger of oxalate of lime coming down here with the excess of the ammonium salt. Furthermore, thorium oxalate tends to dissolve in the hot ammonium oxalate. In this way at least 1 per cent. of monazite (and xenotime) can be detected in the fraction M_4. The amount of other earth minerals which can be detected in this way is doubtful. To the residue left in the test tube after the above filtration is now added a few drops of hydrochloric acid and a very small piece of tin, and the acid evaporated. As dryness is approached, if a tungstate

(scheelite) is present, a characteristic blue color appears in the residue. If much tungstate is present the yellow tungstic oxide can be seen before the blue color develops. This blue color might be due in rare instances to the presence of some niobate decomposable by sulphuric acid. If, therefore, a blue color is obtained, any brown or brownish black grains, particularly any with a pitchy lustre, should be picked out, if possible, and examined with especial care. Titanite, when present in considerable quantity, will impart a grayish color to the residue, and although quite different in color from the blue of tungsten it may obscure small amounts of the latter. With allowances made for the presence of titanite, and *very rarely* of niobates, the tungsten test is delicate to a fraction of 1 per cent.

Tin. — Where the presence of cassiterite (tin stone) is suspected, about 0.1 of a gram of the powdered mineral is mixed with an equal volume of charcoal dust and two of sodium carbonate, and fused before the blowpipe on charcoal. When cassiterite is present, even in small quantities, globules of tin can be obtained with the characteristic white, nonvolatile coating of tin oxide. When black grains are present (in the absence of galena) a yellowish coating of lead may point to the presence of uraninite.

Rather rarely pyrite, chalcopyrite, arsenopyrite, and cinnabar may be found here. These can easily be recognized in most cases by their color or crystalline shape, but if any doubt exists a test for sulphur, arsenic, or mercuric sulphide, made by heating some of the grains in a closed glass tube, is sufficient evidence of their presence.

When sands come from regions where active mining operations are being carried on, pyrite and chalcopyrite are not uncommon, and other sulphides, such as galena and sphalerite, may be found. These last are easily recognized at sight.

If, for purely mineralogical reasons, it is desired to make a more extended and exact determination of the minerals present in M_4 or of the silicate portion of M_3, the following lines of investigation have been found useful by the writer.

First. — A careful fractioning with the Thoulet and barium mercuric iodide solution or with methylene iodide may be made, and in rarer instances, where minerals with specific gravities of between 3.55 and 4.5 are to be separated, the silver thalium nitrate double salt[1]

[1] For a full description of heavy solutions and their use see Mikroskopische Physiographie der Mineralien und Gesteine. H. Rosenbusch and E. A. Wülfing. Part I, pp. 38–50, ed. 1904.

may be used to advantage. The fractions thus obtained can each be examined chemically and microscopically.

Second. — A determination of the relative or even the actual mean refractive index of particular grains is often of service in the identification. For the relative determinations of the index it is convenient to have several liquids of high, known refractive index. The mineral grains, if very small, otherwise fragments of them, are covered with the liquid and the relative strength of the refractive index of the mineral and liquid determined under the microscope by Beck's method.[1] The actual mean index, if lower than the liquids used, may be determined accurately by diluting the liquid about the grain with some solvent of lower refractive index until the indices are exactly matched. The index of the liquid may then be measured. In practice the relative index is, in most cases, sufficient to furnish the information desired. The following liquids have been found serviceable by the writer:

	n
Cedar oil	1.516
Oil of cloves	1.532
Nitrobenzol	1.554
Oil of cinnamon	1.601
Monobromnaphthalin	1.658
Methylene iodide	1.740
Sulphur dissolved in methylene iodide	1.83

Third. — Where the grains are so thick as to render difficult the determination of the strength of the double refraction. Some of them may be imbedded, along with a little quartz or other mineral of known birefringence for comparison, in melted Canada balsam; and when this has hardened they are ground down on a copper lap or glass plate until a thickness is obtained permitting of accurate comparison with the quartz grains and of study with the quartz wedge or sensitive tint.

Massachusetts Institute of Technology,
Boston, Mass., August, 1906.

[1] For a description of this method see Mikroskopische Physiographie der Mineralien und Gesteine. H. Rosenbusch and E. A. Wülfing. Part I, pp. 263–271, ed. 1904.

SHIP MODEL STATIONS

By CECIL H. PEABODY

THE modern competition in shipbuilding, whether for commerce or for war, is so keen that a naval architect cannot consider that he has the correct design for any case unless he has determined the best form of a ship for the required purpose and has accurately apportioned the power to produce the required speed. A failure to obtain the best form will lead to a demand for excessive power, and a failure properly to apportion the power to the speed will lead either to a failure to obtain the desired speed or to excessive weight of propelling machinery, a defect that is equally disastrous if not so immediately evident.

At the present time there is much reliable information concerning ships and their engines in books and periodicals, and it is the habit for governmental and private establishments to systematically record the results of experience, so that they are immediately available for use in making new designs; and yet there is more appreciation than ever before of the desirability of some more direct way of investigating new problems that are continually arising. The most approved method of investigation is to make experiments on models of ships, and to infer from the comparison of the performance of known ships and their models what may be expected from a new design after the corresponding model has been tested. For this purpose experimental stations have been established by the leading maritime nations and by a number of shipbuilders or shipowners, and also at several colleges where shipbuilding is taught. All the stations now established are fully occupied, and it is the opinion of leading shipbuilders that many more could be used to advantage.

The following nations have such stations attached to their navy departments, namely: United States, Great Britain, Germany, Italy, France, and Russia. Two Scottish firms of shipbuilders and one German steamship company have private stations, and another is soon to be installed by a Japanese company. The German station is at Charlottenburg, and its control is divided between the navy and the Technische

Hochschule. The University of Michigan has a station, as has also Cornell University, though it is not known that the latter is fully equipped. During the summer I was able to visit three governmental stations and three private stations; the American station at Washington has been visited several times, but will not be considered in this report except as it may appear proper to make comparisons of the several stations.

Before giving descriptions of the several stations visited, it may be best to give a brief general statement of the methods of testing models and of inferring from such tests the performance of ships. In the first place it may be stated that while the theory of hydrodynamics enables us to study the flow of water past a ship that is under way, and also the forms of waves either in the open sea under the influence of the wind or those made by and accompanying ships, and while such a study is essential to any investigation of the problems before the naval architect, whether experimental or theoretical, that theory does not now and does not appear likely in the future to lead to direct solutions of such problems, on account of their extraordinary complexity. Advance in the science and art of shipbuilding is to be expected from an intelligent observation of the performance of ships and from the use of information thus obtained for new designs. The most potent method for this purpose is the theory of mechanical similitude, which may be considered to be an extension of geometrical similitude to problems of mechanics. An intelligent use of this method, with proper precautions, enables us to infer from the action of a small model what a ship similar to it will do. A most apparent advantage of using such a model is that it may be cheaply made and tested, and that modifications can readily be made; an advantage that is even more important is that the experimenter can have the model completely under his control, and can drive or tow it at any desired speed; and, further, the problems of resistance and propulsion can be treated separately or combined, which is quite impossible under service conditions with large ships. By resistance we mean the force that must be overcome when the ship is driven at a certain speed. The simplest case occurs when a ship (or its model) is towed in quiet water, the resistance being then equal to the pull of the towrope. On the other hand, propulsion of a steamship by paddle wheels or a screw propeller sets in motion a stream of water in contrary direction, which at once disturbs the flow of water past the ship and increases the power that must be applied. It is at once evident that

there is a great advantage in being able to test a model and its propeller both separately and together. It is customary to consider that the towrope resistance (so called) may be divided into two parts: first, the resistance due to the flow of water past the ship, which gives rise to a kind of frictional resistance; and second, the resistance due to maintaining the system of waves that are made by and accompany the ship. Such waves are very evident when any ship is driven at speed, but the form and nature of the waves cannot readily be determined by observations made from the ship or from neighboring objects. In passing, it may be said that a good distant view of the wave can be seen when a ship passes under a high bridge, such as that at the Firth of Forth. It has been proved that the form and location of such waves, where they are in contact with the hull of a ship, have much to do with her resistance, and a study of them can be best made at a model testing station. As for propellers, they can be studied separately only at model testing stations, and such tests have brought order out of chaos, though there yet remains much to do both in theory and practice.

During the design of the *Great Eastern*, William Froude, Esq., was obtained by Scott Russell to make certain investigations by the aid of models to determine the probable behavior at sea of that ship. Afterwards the attention of the British Admiralty was called to his work, and a grant of money was made to establish a station for towing ships' models at Torquay near his residence about the year 1872. Investigations were made at this station by William Froude and by his son, R. E. Froude, who is now the scientific expert to the Admiralty. In the year 1886 a new and improved station was established by the Admiralty at Haslar, just across the bay from Portsmouth. It is not too much to say that the investigations of the Froudes, father and son, have done more for the development of scientific shipbuilding than any other single influence.

It was, therefore, with the greatest pleasure that I learned of the favorable answer to my request to see this station, which had been made through the American embassy, especially as arrangements had been made for me to meet Mr. Froude at that place. The very universal favors that were shown me at that time are to be credited to the kindness of Sir Philip Watts, K.C.B., Chief Constructor to the Admiralty, to whom I was introduced by Professor J. A. Ewing, the Director of Education to the Admiralty.

The station at Haslar is the prototype of all the model towing

stations, and is very closely copied by all other European stations; consequently it will be described at some length, and the descriptions of other stations will give only such features as differ from the prototype. The description must be in general terms to avoid making the report too technical and tedious; as there are excellent detailed descriptions of this station and its details, there is less reason for prolixity.

To provide for towing the models there is a canal or tank 400 feet long, 20 feet wide, and 10 feet deep, with vertical masonry side walls. On these walls are laid steel rails like those of a railway, except that the gauge is over 20 feet instead of the conventional gauge of 4.7 feet. A carriage spans the canal and carries the observers and the apparatus for towing the model and making the proper records. The pull required to tow the model is measured directly by a helical spring, and the deflection of this spring is multiplied by proper mechanism and is recorded on the drum of a chronograph, on which are made also records of times and distances. Since the extreme accuracy of the astronomical chronograph is not necessary for this work, it is found sufficient and convenient to drive the drum by gearing from the axles of the carriage. The time is measured by a chronometer, which beats half seconds and makes and breaks an electric current that operates a pen on the chronograph in the usual manner. Along the side of the canal are electric contact pieces at regular distances that enable the carriage as it passes to make an electric circuit and make a record on the chronograph which, with the time record, gives the means of determining the velocity of the carriage. There is also a device for determining and recording the change of trim, that is, the rise of the bow and depression of the stern, that usually takes place when a boat is driven at speed.

The carriage at Haslar is made of pine wood, so arranged in the form of hollow box girders as to be at once very light and stiff. It is towed by a wire rope, which is wound up by a steam engine with a special governor, devised by William Froude, to bring the engine quickly to its desired speed and to maintain a uniform speed. Having found that the longitudinal elasticity of the wire towrope gave rise to troublesome oscillations, a hydraulic cylinder and piston were interposed to act as a dampener.

The free course of the carriage is reduced by necessary arrangements at the ends for convenience in adjusting the model and the

carriage to 380 feet or less, which at some speeds is traversed in about twenty seconds. The carriage must be quickly brought up to its proper speed in order to give a reasonable time for making records and for stopping safely at the end. In preparing for a test, the probable pull on the spring is estimated and stops are set wide enough apart to give necessary freedom and provide for oscillations, but near enough to avoid undue extension and violent oscillations. While the carriage is started a rigid stop is thrown in which carries the pull required to accelerate the model, and this stop is not thrown out till uniform speed has been attained.

To arrange for testing propellers a second carriage is provided, which can be attached behind the towing carriage with devices for measuring the turning moment applied to the shaft of the propeller, the number of revolutions per minute, and the thrust due to the action of the propeller on the water. A proper chronograph is provided for recording these several actions. If the ship model is omitted, experiments can be made on the propeller in undisturbed water; with the model in place and the propeller properly related to it, the interaction of ship and propeller can be investigated.

It is needless to say that apparatus must be accurately made, delicately adjusted, and skillfully used in order that valuable results may be obtained.

The models are made of paraffin, with the addition of 3 or 4 per cent. of beeswax, as that substance is readily molded to an approximate form, is readily cut to the exact shape, and may be burnished to a smooth surface which is not affected by water. In preparation for casting a model, a mold is made in modeling clay which is about $\frac{1}{4}$ inch larger than the finished model. A kind of canvas canoe is made to determine the inner surface of the model, leaving a thickness of about $1\frac{1}{2}$ inches to be filled with paraffin. The cotton cloth of this canoe is painted with modeling clay to prevent flow of hot paraffin through it, and then melted paraffin is run in slowly, there being considerable shrinkage on cooling, which must be made up by running in additional paraffin. As the mold is filled, water is run into the inside of the canoe to counteract the hydraulic pressure of the paraffin and to aid in cooling. The model is carried to a convenient height above the level of the water line at which it will float, and is finished at the top to a plane surface, with four projecting lugs on each side to aid in determining the draught and trim of the model when ready for testing. For this purpose hook

gauges are hung in pairs on the two corresponding lugs on the port and starboard sides, by aid of which the adjustment to the proper level can be made with great accuracy. The model is cut in a profiling machine resembling a planing machine, with a table that can be traversed back and forth under a frame which supports a pair of revolving cutters. These cutters are much like those used for cutting wooden moldings, but the edges are keener, and they are driven at very high speed, as they operate on a soft material. The model is properly centred on this table, and the cutters are adjusted to the height of a "water line," or horizontal section; then they are guided in such a manner as to cut a groove on each side down to the proper surface of the model as it is moved with the table past them. The redundant material is afterwards pared away by a skillful model maker, and the surface is faired and smoothed to the correct form. The device which was invented by William Froude for tracing water lines is worthy of description, as it is simple and effective. In the first place, it may be premised that the cutters can be simultaneously drawn together or moved outward from the centre line of the model by turning a handwheel conveniently placed at the side of the machine. This motion is communicated to a pantographic device which moves a tracer over a drawing of the water line of the ship (usually on a smaller scale than the model), which is pinned to a drawing board which reciprocates with the model, but at a slower speed commensurate with the reduced scale of the drawing. As the cutter is a circle, the tracer is also a circle drawn to the scale of the drawing. Starting at the middle of the model, the operator draws the cutters together till the tracer touches the proper water line. He then starts the table of the machine, and as the drawing board moves under the tracer he continually draws the cutters nearer, keeping the tracer in contact with the water line, and thereby profiles the groove for that water line from the middle to one end of the model — the bow, for example. Returning to the middle, he performs a like operation for the stern. There are two very ingenious devices to ensure correct and certain action of these cutters. In the first place the drawing, however carefully made, may not have its base line, as pinned to the board, exactly straight; consequently a wooden straight edge is clamped on to the base line and bent to conform to any slight inequality it may have. Then the pantograph is made with two parts, one of which bears against the wooden base line and the other carries the circular tracer; consequently the operator is virtually meas-

uring the half breadth of the model (which is not likely to be affected by handling the drawing) and transferring it to the cutters. Should the operator fail to trace the line correctly, it is most likely that he will leave redundant material which can be removed by tracing the line again, or it may be cut away by the model maker. To give more complete control the table is not driven directly from a source of power, but is driven by a hydraulic device which continually pumps water through an open valve. The operator may close this valve at pleasure by pressure on a foot lever, thereby producing pressure on a piston which actuates the table at any desired speed. The operator has, therefore, complete control over the cutters and the table, and can work as fast or as slowly as he desires; and if he hesitates he probably does no more than fail to cut deeply enough, a defect that he may remedy immediately by reversing and tracing over again. Being allowed to try the machine, I found that a little practice was sufficient to give decent execution, and I am convinced that the method gives all needed accuracy. In fact, it was stated by an attendant that the error was commonly not more than one-tenth of one per cent.; he thought that three-tenths would be "a lot."

Experimental propellers are made of an easily fusible composition of lead and tin, with a little bismuth. They are conveniently made by first preparing a true helical surface of plaster of Paris; on this the contour of the blade is drawn, and the blade, with proper thickness, is molded in wax. The plaster is set with the helical surface uppermost, and liquid plaster is poured on and allowed to harden; when the two blocks of plaster are separated and the wax blade is removed there will be in hand the two halves of a mold for casting the blade. Clearly two, three, or four blades can be prepared in the same way, and the assembled molds, with provision for the hub of the propeller, can be used for casting an entire propeller. The surfaces of the casting are scraped smooth, but the form is changed as little as may be. The contour of a blade, as drawn on the true helical surface, is an ellipse (as nearly as the circumstances admit) for propellers of usual proportions. Where very large blade surface is demanded, as for torpedo boats, to avoid discontinuity of the water acted upon by the propeller, the blade is widened at the end and approaches the early form with straight edges, such as is commonly used for towboats. The elliptical form has been shown as the standard by the British admiralty. The American Navy Department has selected a form that is somewhat more rounded at the end.

Experiments on propellers at Haslar show that when driven in open water much loss of efficiency is felt if a large hub is used. Adding a headpiece does not much reduce this difficulty. But propellers on ships do not lose efficiency in like proportion when large hubs are used, because the water is guided to the propeller by the form of the ship, including the bosses surrounding the propeller shafts.

One of the most important series of problems affecting propulsion is the investigation of the wake (or stream of water dragged along with a ship by friction against the sides of the ship), the effect of this wake on the efficiency of the propeller which works in it, the disturbance of this wake by the propeller itself, and finally of the best arrangement of the propeller for a certain ship. From what has been said it will be seen that an experimental tank gives opportunity for investigating these problems for a model. Unfortunately the conditions are not exactly the same for a ship and its model when towed or driven at corresponding speeds, especially as the model has much more wake than the ship, as is shown from comparison of progressive speed trials on a ship and tank tests of her model. For sake of comparison it is customary to draw wake diagrams for the ship and her model in a method that cannot be adequately described here. It is sufficient to say that such diagrams are found to be similar, though not similarly placed, and that a comparison of the diagrams for a certain ship and her model allows a skilled observer to infer from the diagrams of a model what the conditions for a ship built on that model will be. Mr. Froude thinks that, on the whole, the comparison is as good as such a method warrants, and is a reliable guide for determining the problems of speed and power.

It has long been known that forms that are adapted for high speed in smooth water may not be seaworthy or (even if quite safe) may not give the best speed in rough water. This fact has been considered by some shipbuilders to cast doubt on the value of model experiments, and also on progressive speed trials, which are always made in smooth water. In order to investigate the effect of rough water on speed, Mr. Froude has made experiments on towing a model of a cruiser among artificial waves in the experimental tank. It may be sufficient to say that he finds that for a cruiser the best results are obtained by so drawing out the bow as to give a slight hollowing of the water lines It should be remembered that all warships carry their guns at a considerable height above the water, and for that reason must be given

greater beam than have merchant ships, which carry their principal weight in the hold. Consequently the conclusion which holds for cruisers may not hold for passenger ships. The model which was tested under the given conditions was seen at Haslar, and the apparatus for making waves was in place and was set in operation to exhibit a number of interesting features of the waves made by it.

By the trochoidal theory of waves each particle of water is assumed to revolve in a fixed orbit; the orbits are assumed to decrease in diameter rapidly with the depth below the surface of the water; it is also assumed that all the particles which have the centres of their orbits in a vertical line revolve together and come to the tops of their orbits (or any other corresponding parts) at the same instant. A curve drawn through corresponding points of such a set of orbits is called a dynamical vertical. If a model were made to revolve a series of points in properly arranged orbits, and if a slender rod were passed through those points, that rod would be seen to wave back and forth, something like a stalk of grain in the wind, though the comparison is far from exact. Such a rod would represent a dynamical vertical. Now Mr. Froude has placed a wooden frame or diaphragm about 2 feet wide across the further end of the tank, and has arranged cranks and rods to give the frame a motion approximating to that of a dynamical vertical of the wave he desires to produce.

When this apparatus was started the waves showed a series of surface wrinkles or surface tension waves; the peculiarity of these waves is that the faster they run the shorter they are, and short waves are rapidly dissipated by viscosity; therefore when the apparatus was well under way at its proper speed the wrinkles disappeared. If the apparatus was run a short time and then stopped it generated a group of waves; one could easily walk along with the group and determine the fact that the velocity of the group was approximately half that of any individual wave. The apparatus was then set to give waves that tended to run up to a head and break, and observation showed that the crest just before breaking had a sharp edge like the roof of a house, the angle at the apex being about 120°. These three several phenomena all agree with the hydrodynamic theory of waves. It was most curious and interesting to note that an attempt to make a trochoidal wave resulted in forming a wave which at its maximum height had a crest with an angle of 120°, as is shown by Stokes to be proper for an irrotational wave, the more so as mathematicians object to the

trochoidal theory of waves, inasmuch as it is rotational and therefore cannot be generated by weight and pressure only as sea waves are supposed to be. It is further interesting to remember that the form of sea waves is much more like a form deduced mathematically by Stokes for irrotational waves than they are like trochoidal waves. However, the two forms approach as the heights decrease, and with moderate heights are hardly distinguishable.

The water for filling the tank was taken from the local town supply, and is renewed only to make up losses by evaporation and otherwise. The first summer after the tank was established there was a very annoying growth of weeds. Each succeeding year the growth diminished, though nothing was done to that end, and now the growth is not troublesome.

The second experimental model station to be established was that at the Leven shipyards, at Dumbarton on the Clyde. It is now the oldest station, as it was established in 1884 on the model of the original station at Torquay; this, together with the fact that it was the first station for private work and the fact that it has since been used uninterruptedly, gives it an unusual interest. Its dimensions are: length, 300 feet; breadth, 20 feet; draught, 8.8 feet. Like the Torquay station, the rails for the carriage are slung from the roof, and they have a gauge of only 4 feet. The carriage is drawn by a wire rope, and there is no apparent intention of substituting electricity. The carriage being very light, there is no difficulty from longitudinal oscillation of the rope, which is attached directly. By the aid of this station the firm has the more easily taken a leading position, especially in certain difficult fields, like the building of high-speed paddle steamers and the application of steam turbines. In 1888 the firm desired to bid for a paddle steamer 300 feet long and with a beam of 35 feet, which was required to make 19½ knots (at the time an exceptional speed), and in order to have an advantage wished to increase the speed to 20½ knots. At first the scientific staff were unwilling to undertake a higher speed than the specifications called for, that is, 19½ knots; but, after trying a number of models in the tank and changing proportions of the hull and the arrangement of the paddles, they concluded that it would be safe to guarantee 20½ knots as the firm wished. In fact, they found that a better speed could be expected, and their conclusions were verified on trial of the ship, which made the unprecedented speed of 21.6 knots.

The records of the station include a vast amount of information, which is very properly considered to be a part of their stock in trade, and which is not available to the profession in general. A member of the firm expressed the opinion that every important firm could profitably maintain a station for its own work, and that such a station would have little time for outside work even if there were no objections to such use of the station; in fact, he thought they could keep a second station busy if they had it. This opinion is quite contrary to the idea that an open or public station should be maintained by the government or in connection with a technical college, at which models for various shipbuilders could be tested. Such a station, however, was favored if it could be employed in general scientific work that should be useful to the entire profession. For example, it could determine the best form of lines for various proportions and speeds, a piece of work which must now be undertaken by each station on installation before it is in condition to attack special problems advantageously. At one station, which has been more recently installed, such work is in progress and must take much time and energy which could be more profitably employed if general information of that nature were in possession of the profession in general. The investigation of propellers, their proportions, and their efficiencies has been carried out many years ago at Haslar and more recently at Washington and at Cornell. In passing, attention can be called to the fact that a properly equipped station at the Institute of Technology could at once undertake such scientific work to advantage, and would probably be able to get enough work from shipbuilders to enable it to keep the proper correlation with the performance of full-sized ships, and thus avoid any chance of wasting effort in barren academic investigations.

The second governmental station visited was that belonging to the Italian navy situated at Spezia. It was installed in 1889 and differs from its prototype at Haslar only in minor details. In particular, the instrument maker has substituted brass and steel for wood in places, and has produced apparatus which at first sight looks like an improvement, but second thought leads to the question whether the earlier construction under the eye of those who developed this method of investigation, and who could not have lacked means for such construction as they preferred, has not good reason in every case for the material preferred.

A large amount of excellent work has been done at this station, and

much liberality in publishing has been allowed. In the first place we have "La Vasca per le Esperienza di Architecture Navale," etc., by Colonel Giuseppa Rota, a copy of which was presented to the Institute of Technology and is now in the library of the department; and other tests, notably on the effect of shallow water on resistance, have been published by the same author in the *Transactions of the Institution of Naval Architecture of Great Britain.*

As this station is exposed to much the same climatic conditions as are found at the Washington station, it is very interesting to find that they use paraffin for models without difficulty. Of course the models are kept immersed when not in use, as is always customary when paraffin is used. Captain Bonfiglietti, who was stationed at Spezia when that place was visited, expressed the opinion that the real difficulty in the use of paraffin was experienced when the models took large dimensions, like 20 feet in length, and it arose from unequal expansion of the under and out of water parts. This statement may be compared with the practice of using models made of paraffin, 21 feet long, at Berlin.

The method of making propellers at this station differs from that already described in connection with the description of the Haslar station. Here they begin by making drawings of the propellers to a convenient large scale, including transverse sections of the blades. These drawings are reduced photographically to the proper size for the model propellers. Wooden models are then made from these reduced transverse sections, and these models serve for molding and casting the propellers, which are made of the customary composition of lead, tin, and antimony. The models are finished by hand, and are tested by aid of a surface plate and a surface gauge under a magnifying glass.

Perhaps owing to the climatic conditions much trouble was formerly experienced from the growth of weeds, but that trouble has been entirely avoided by the use of copper sulphate in the proportion of one to three hundred thousand.

The carriage at this station is drawn by a rope, just as at Haslar, but there is a proposition to substitute electric motors.

The North German Lloyd Steamship Company have a model towing station at their principal harbor, Bremerhaven, which was installed in 1900, and which has been used primarily for determining the best forms to be given to their new high-speed passenger ships; but it has also been used for investigations of models of warships for almost all the Continental maritime nations, including Russia, which has a station

established thirteen years earlier. The carriage at this station is framed of vertical steel tubes and diagonal tie-rods, and appears to be both light and stiff. It is driven by electric motors, there being two of 6 horse power each. The station is maintained in excellent condition, and the work appears to be thorough and systematic, as might be expected in Germany. The fact that the work has been for governments and for certain private firms explains why there has been little published from this station.

At Charlottenburg, near the Technische Hochschule, there is a station which is owned in common by that institution and the German Admiralty, the navy having exclusive control during a certain part of the year. At the time when this station was visited it was under the control of the navy, while my introduction through the proper channels was to the school. On proper explanation the attendants in charge allowed me to see the work in progress, which was the determination of resistance of a ship in a shallow, restricted channel like a ship canal. They had an apparatus for testing four screw propellers simultaneously; it was said to have proven to be satisfactory, but no encouragement for careful inspection was given. As this station was completed in 1902, and has had the disadvantage of double ownership, it may not be reasonable to expect much in the way of published results as yet.

Paraffin models are used at this station, having lengths as great as 21 feet, though at Haslar and at Spezia lengths greater than 12 feet are deprecated either on account of the weakness of the material or its tendency to soften at high temperature. Summer temperatures at Berlin are liable to be high, though continued heat is not so likely as at Spezia or Washington.

The tank or canal at all the four stations previously mentioned is nearly rectangular in section, there being only a slight concavity of the bottom or rounding of corners But at Charlottenburg the bottom is much rounded, being about 11½ feet deep in the middle and only 6½ feet deep at 10 feet from the middle; from this point of the section the contour is somewhat irregular, but there is in effect a bench at each side 6 feet wide on which the mean depth of the water is only 4 feet. The rails for the carriage are carried by columns at intervals, which has been found to be undesirable, and side walls are to be carried up under the rails, which will reduce the maximum width from 34.5 feet to 20 feet.

The carriage is made of small angle framing and appears to be

light and stiff. It is towed by a separate motor carriage in front, which carries two 10 horse power motors.

The last model station seen was that established at the yard of John Brown and Company at Clydebank, in 1904. It follows the dimensions and construction of the station at Haslar very closely, the principal difference being an appreciable increase in length. A considerable part of the work of the station to the present time has been the accumulation of stock in trade, and there is yet much work of that sort to be done which might have been avoided in large part if such material were published.

Though the experimental model basin at Washington belonging to the Navy Department was not seen this past summer, it may not be out of order to speak of it in this place. It was finished in 1898, and has since done much important work for the determination of the best form for our naval vessels, and there have been most important investigations of the action and efficiency of the propellers, which are more complete and on a larger scale than any similar work. It is not too much to say that when the data with regard to propellers is completed and systematized it will replace all other work of that nature. As for the work on models of ships for the navy, it is reported that the saving from the reduction of engine power for one class of battleships in consequence of improvements in form was enough to pay for the entire station.

The station is under the direction of Naval Constructor D. W. Taylor, U.S.N., the work of observation being carried on by Messrs. Curtis and Hewins, alumni of the Institute of Technology from the department of Naval Architecture.

The station has been described in the *Transactions of the Society of Naval Architects and Marine Engineers*, in which are found published results of investigation made there. It may be sufficient to say that it has been built in the most thorough manner, with every appliance for refined investigation. For various reasons it was decided to make models of wood instead of paraffin, especially as the models are all about 20 feet long, or about twice the length that had been previously used. The method of forming the models is quite different from that used for paraffin models, involving the construction of an entire, full-sized model, with sections and planking much like a carvel-built skiff, which model is used as a former for the profiling machine which cuts the model to be used in the tank.

When possible, tests are made for such private firms as may desire such work, the charge being as near as may be equal to the expense incurred by the station. Such work is, however, limited, because the work for the Navy Department and on scientific investigations which are considered essential for the prosecution of that work keep the stations well employed.

MODERN FLOATING DRY DOCKS[1]

By CIVIL ENGINEER A. C. CUNNINGHAM, U.S.N.

General perfection in floating dry docks was reached with the type first and still known as the "balance dock," which is also called the "solid dock" since the introduction of sectional and self-docking docks. The sketches in Diagram 1 show a plan, end, and side elevation of a

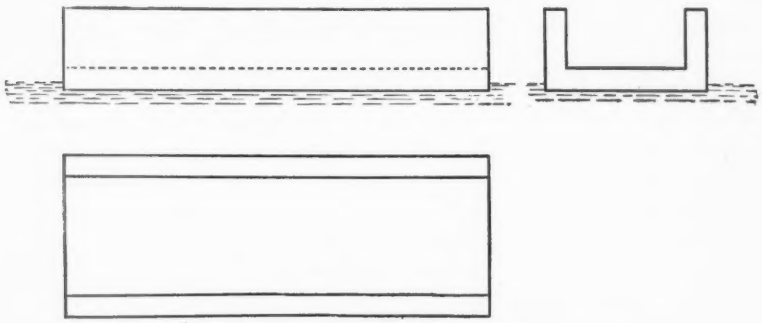

Diagram 1.—The Solid Dock

balance, or solid, dock. In pumping up one of these docks, the trim may be maintained by regulating the amount of water retained in the side walls, which gives the name "balance dock."

These docks were originally and are still constructed in wood, and the inner faces of the side walls are generally given a batter to secure greater transverse stiffness of construction. In wood construction the dimensions and capacity of a solid dock are comparatively small on account of the weakness of the connections and limited strength which naturally accompany the material.

The general cross section of the balance dock has prevailed through all subsequent forms of floating docks of recognized merit, and the more

[1] A lecture delivered before the class of Naval Architects at the Massachusetts Institute of Technology in March, 1906.

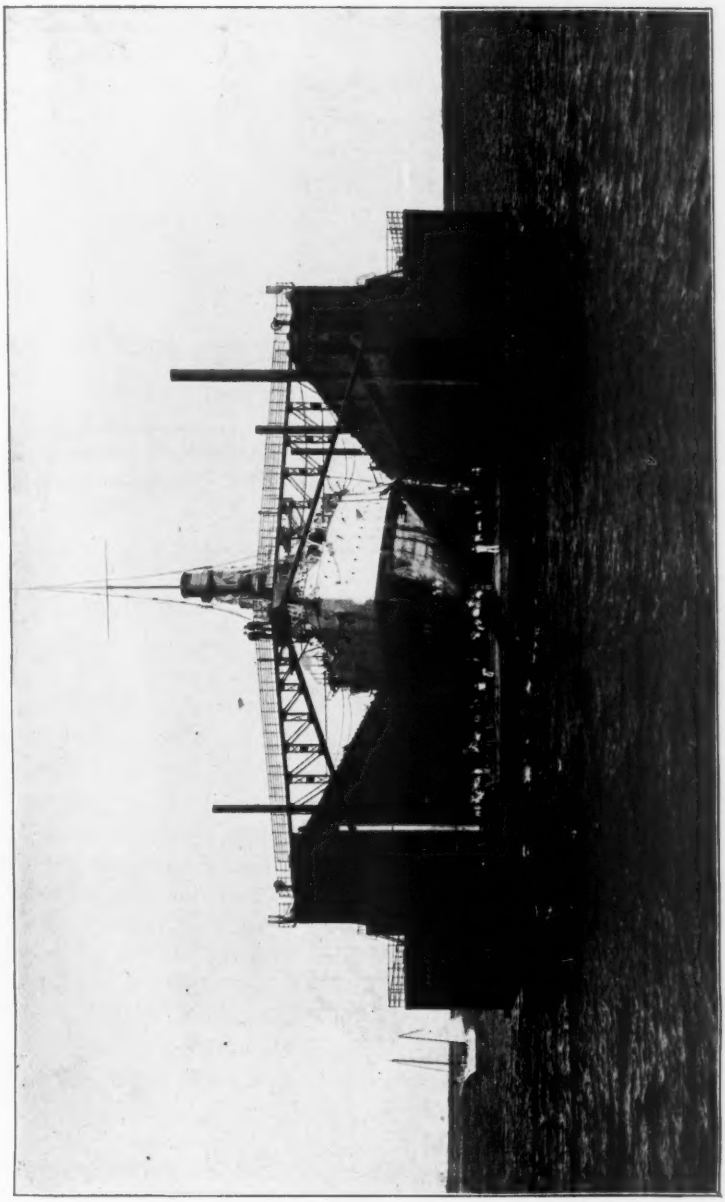

PLATE I.—U. S. FLOATING DRY DOCK "DEWEY," WITH THE BATTLESHIP "IOWA" COMPLETELY DOCKED

closely a modern floating dock approximates to the original balance type the greater its value.

When a solid floating dock reaches dimensions which prevent its entrance into a land dock for repairs, its life becomes limited. In wooden docks this life is of sufficient extent to return a profit on the investment, but it would not be with a steel dock.

The solid dock was closely followed by the sectional dock, which is simply a series of small solid docks loosely connected together merely to preserve the alignment. The advantages of the sectional dock are that one section can be repaired upon another and, in wood construction, a much longer dock can be made operative than would be possible with a solid dock of the same material; an incidental advantage is that the sections may be divided into groups.

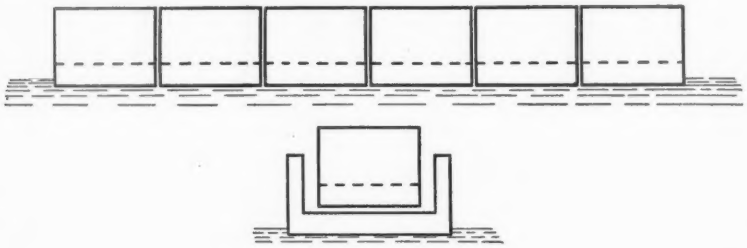

DIAGRAM 2.—A SECTIONAL DOCK

In Diagram 2 is shown a side elevation of a sectional dock of six sections which can be subdivided into various groups for independent use at the same time, and also a sketch showing one section turned 90° and docked on another. The disadvantages of a sectional dock are the great care necessary to preserve the alignment and the difficulty of so adjusting the lifting force of each section that the docked vessel shall not be unduly strained or injured. No solid or sectional docks of any extensive magnitude have been constructed of wood.

Diagram 3 shows a modified form of sectional dock in steel construction. Figure 1 is a side elevation of the dock in alignment ready for operation. Figure 2 shows one section docked on the others. A notable dock of this construction is that of Blohm and Voss, in Germany, which has a lifting capacity of 17,500 tons.

From the elevations it will be seen that this sectional dock in steel lacks continuity, and that the self-docking of the sections is a rather precarious proceeding.

The construction of floating docks of any great magnitude in iron or steel requires that it should be possible to have access to the under water portions for preservation and repairs. This led to the development of the general type known as self-docking floating dry docks. As the modern ship of the first class, and especially the warship, is a flexible and tender structure as compared with its short, broad predecessor in wood, it was necessary that these self-docking docks should have the greatest possible continuity and longitudinal stiffness. The sectional dock, pure and simple, has, in consequence, been eliminated from the problem, and an approximation to the solid or balance dock is always sought.

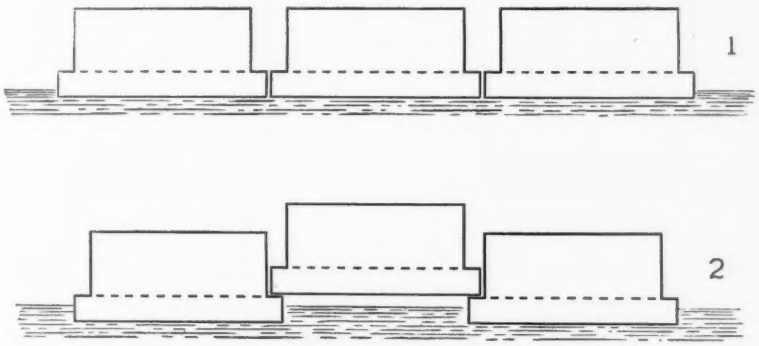

Diagram 3.—A Sectional Dock of Steel Construction

The first self-docking dock of any note that is still of importance is known as the Rennie dock, after Mr. George B. Rennie, the celebrated English engineer.

The Rennie dock is illustrated on Diagram 4. Figure 1 is a plan showing a pontoon being withdrawn preparatory to self-docking. Figure 2 is a sectional side elevation showing a pontoon self-docked. Figure 3 is an end elevation showing a pontoon self-docked.

This dock is a compromise, having the side walls of a solid dock and the pontoons of a sectional dock. For very great longitudinal stiffness the side walls must be unusually high and wide, as any extensive or strong connections between the pontoons are impracticable. The dock has the advantage of being easily constructed; the pontoons can be built and launched separately, assembled after they are afloat, and the side walls then erected on them in place. The self-docking is simple in principle and requires no technical skill or instruction.

The pumping of a floating dock is accomplished with centrifugal pumps, which should be placed as low down in the structure as possible, in order that they may not lose their priming in the last stages of pumping. These pumps discharge directly outboard at their own level. As regards pumping plant, the Rennie dock is at a disadvantage. For economical construction the pumps must be placed in the side walls above the pontoons, and therefore have a long suction in the last stages of pumping, which, if necessarily stopped, may lead to a loss of priming which may be difficult to restore.

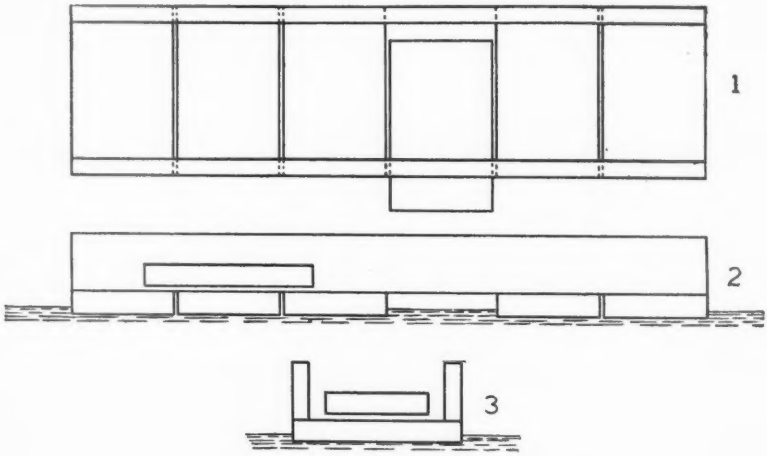

DIAGRAM 4.—THE RENNIE DOCK

A number of important docks have been built on this principle; others are under construction and design in Europe, and the type will always be of importance on account of the ease and simplicity of construction.

The next dock requiring consideration is the Clark type, designed by Mr. Lyonel E. Clark, of the firm of Clark and Standfield, of London. The members of this firm are both descendants of a line of celebrated floating dock designers and builders, and have done more towards advancing the interests and value of floating docks than any other individuals in the world.

The Clark dock is a modification of the Rennie dock, and is illustrated in Diagram 5. Figure 1 is an end view, in which it will be seen

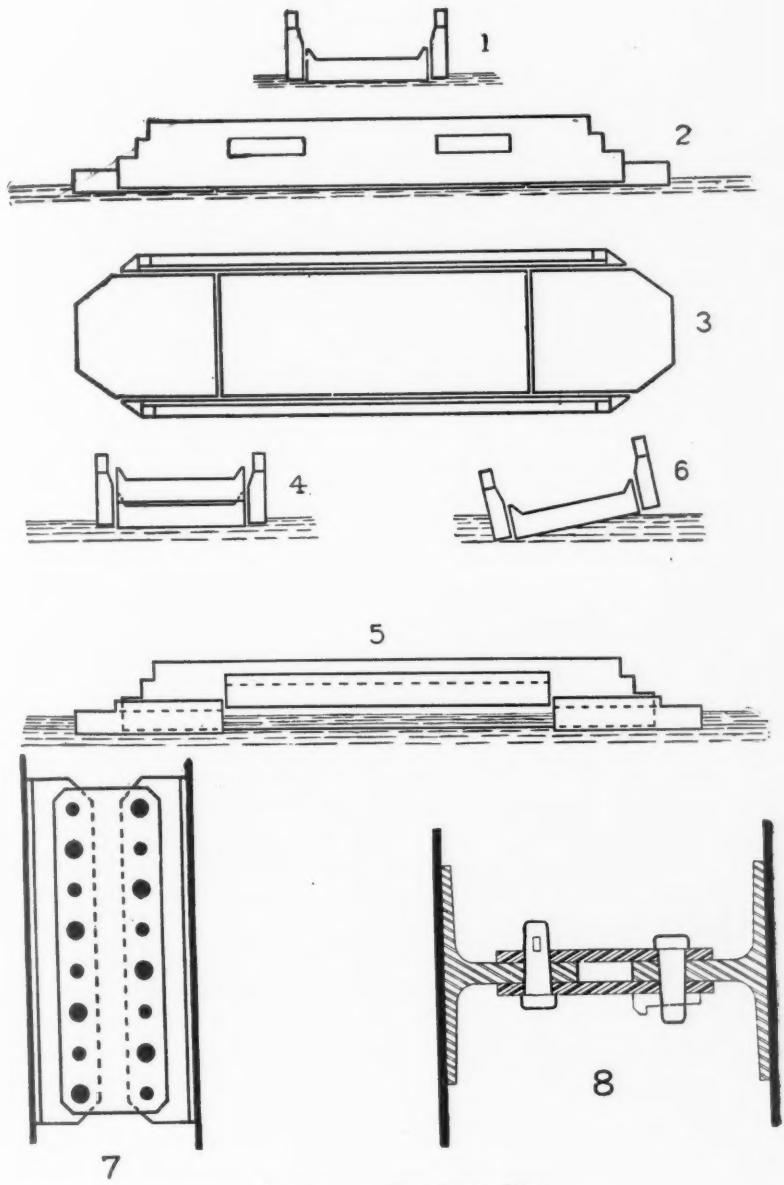

DIAGRAM 5.—THE CLARK DOCK

that the pontoons are placed between the side walls instead of under them. Figure 2 is a side view showing the manner of stepping back the side walls and the gangway openings to which Mr. Clark has so far generally given preference. Figure 3 is a plan showing the pointed end pontoons preferred by Mr. Clark. Figure 4 is an end view showing the end pontoons self-docked. Figure 5 is a sectional side view

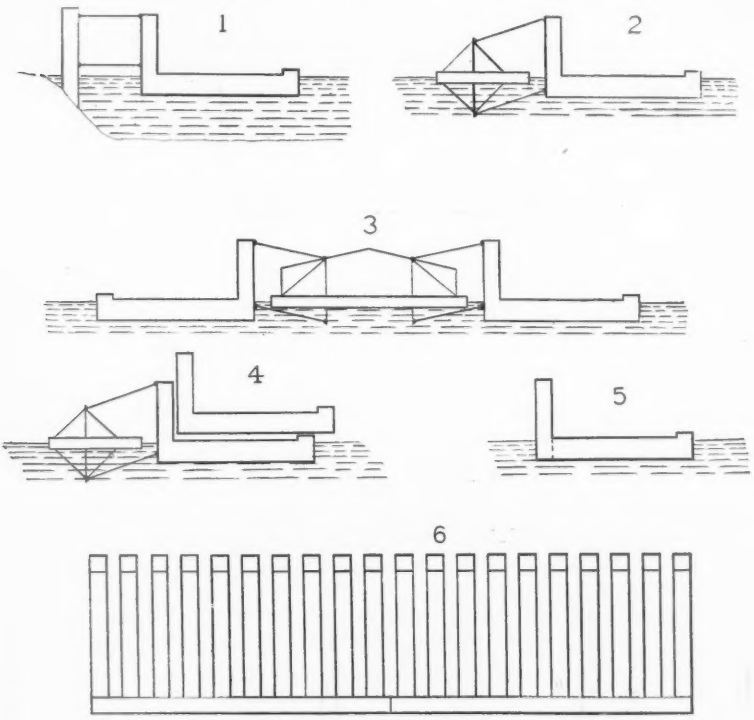

DIAGRAM 6.—OFF-SHORE DOCK

showing the central pontoon self-docked. Figure 6 shows the manner of getting at the bottom of side walls. Figure 7 is a detailed elevation, and Figure 8 a detailed plan of the numerous taper-bolted tee and fish-plate connections between the pontoons and side walls.

In this dock Mr. Clark has sacrificed the simplicity of construction and ease of self-docking of the Rennie dock to securing greater longitudinal strength and stiffness with practically the same material.

It is apparent that for Clark and Rennie docks of the same general dimensions the increased depth of side wall in the Clark dock gives much greater longitudinal stiffness. In the earlier Clark docks five pontoons were used, so that there was not much gain in continuity of floor over the Rennie dock; but in later designs Mr. Clark has reduced the pontoons to the least possible number — three — so that with the long central pontoon the Clark dock has a much stiffer and more nearly continuous floor than the Rennie dock. In the pumping plant Mr. Clark also has the advantage of having the pumps located well down near the bottom of the structure. In locating the pontoons between the side walls the lower connections have been placed in a position where they are normally under water and inconveniently located for inspection and preservation. To bring the upper connections to a suitable height, altars must be added to the pontoons, which decrease the floor space and complicate the construction.

The self-docking of a Clark dock requires skill and technical knowledge. The connections being all in vertical shear, the various combinations of side walls and pontoons used in self-docking must all be brought to the same flotation and buoyancy before the connections can be opened. The accumulations of mud in the pontoons and marine growth on the outside constantly vary the flotations of the separate parts, and the cantings of the dock for partial and progressive openings of connections make it desirable that the self-docking should be under technical supervision.

Another type of dock designed by Messrs. Clark and Standfield is called the "one-sided" or "off-shore" dock. The dock may be attached to a floating outrigger or to a framework on the fore shore by booms having a parallel-ruler motion. It is generally made in two sections. The dock is illustrated in Diagram 6. Figure 1 is an end view of the dock attached to a framework on the fore shore. Figure 2 is an end view of the dock attached to an outrigger. Figure 3 is an end view of a proposed double dock of this type with floating outrigger between. Figure 4 shows the simple method of self-docking. Figure 5 is an end view of a modification of this dock, called a "depositing" dock, with which a ship is lifted and placed upon a grid. Figure 6 is a plan of the depositing dock. The one-sided dock is well suited to ships having considerable inherent stiffness and no greatly concentrated weights. It is very convenient in narrow streams, as the ship can be taken on sideways. No shoring is possible on the off side, and in

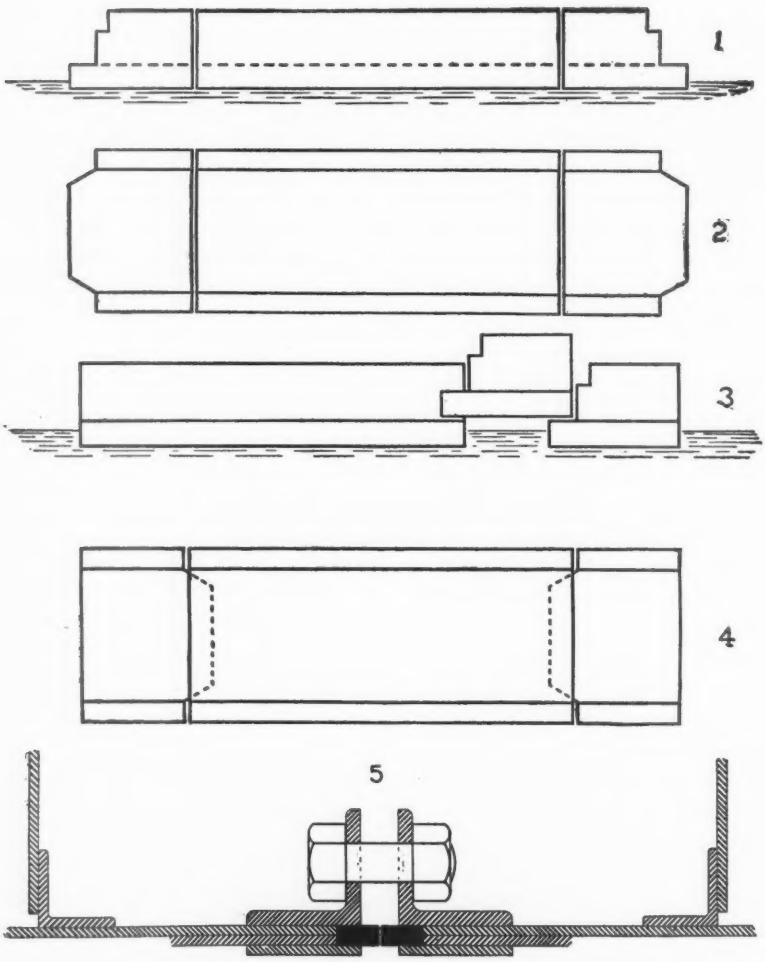

DIAGRAM 7.—BOLTED SECTIONAL DOCK AT POLA

pumping up, care must be exercised to prevent a side launch or rolling over.

These one-sided docks cannot safely be used without their shore attachment or outrigger, as the omission of one side wall destroys the "balance" property. As soon as the pontoons are submerged, the shore attachment must be depended upon to preserve the trim, as

slight variations in buoyancy are not resisted and controlled as in the case of a two-sided dock. For the same reasons the pumping must be done uniformly and with care, in order not to cause a dangerous strain in the shore connections.

The latest design of self-docking dock made by Mr. Clark is a bolted sectional type for the Austrian Naval Station at Pola. This dock

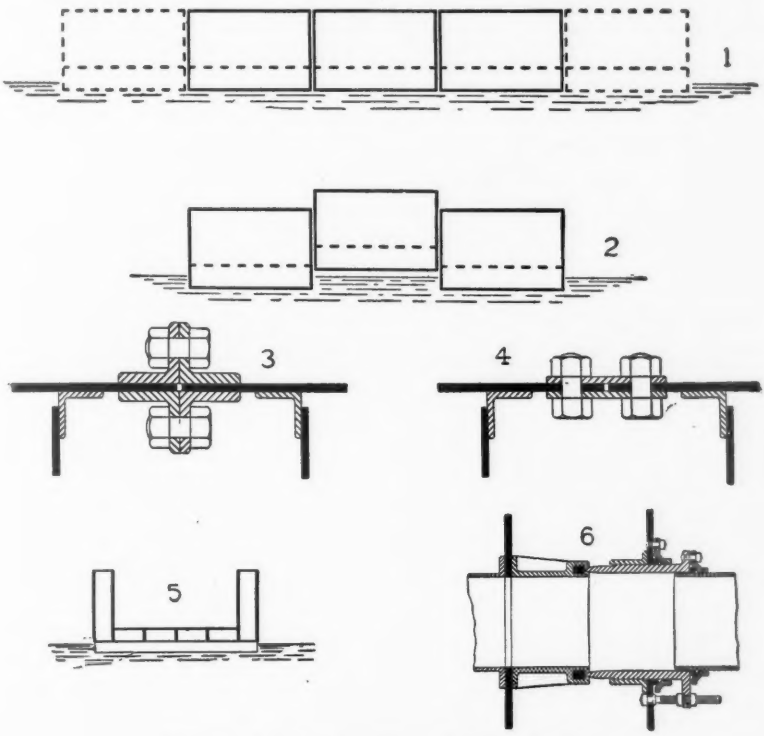

DIAGRAM 8. — THE CUNNINGHAM SECTIONAL DOCK

is illustrated in Diagram 7. Figure 1 is a side elevation. Figure 2 is a plan. Figure 3 is a sectional side elevation of an end section self-docked. Figure 4 is a plan of the central section self-docked. Figure 5 is a detail section of the chamber between sections which extends continuously around the sides and bottom.

The location and extent of the connections between the sections of

the dock make it practically continuous and the nearest approximation to a solid dock that has yet been devised. This dock has not yet been self-docked, so far as can be ascertained, and considerable doubt exists as to the possibility of making or keeping the chambers between the sections dry, so that the connections will be accessible.[1]

The self-docking of this dock is very similar to that of the modified sectional dock first described, except that, owing to the necessarily pointed ends of the end sections, less stability is secured.

The self-docking docks so far described are all of foreign design and represent the progress so far made in the matter in Europe.

Since the revival of general interest in floating docks in the United States further progress in the matter has been made in this country. The progress is based upon experience with the Clark dock and study of all existing and proposed types.

On Diagram 8 is shown a modified bolted sectional dock proposed by myself about three years ago. Figure 1 is a side elevation of a dock begun with three sections and later extended to five (two new ones dotted). Figure 2 is a side view showing the method of self-docking. Figures 3 and 4 are details showing different manners of connecting the sections. Figure 5 is an end view showing the lines and extent of connections. Figure 6 is a detail showing the connection of the pumping main between sections. In this type each section is a complete and independent dock in itself, and all sections are alike. The dock has the same advantage as the Rennie dock in that the pontoons can be built and launched separately, the side walls erected on them after they are afloat, and the sections finally assembled and connected. When connected up the entire dock can be operated from the pumping plant on one section. The possibilities of extension or separation into groups with this dock are of considerable importance commercially. The self-docking is simple and requires no special instruction or technical knowledge.

A disadvantage of the dock is that the pumping must be regulated from as many stations as there are sections. The repetition of sections does not give as great economy in disposition and location of material as is possible in a solid dock, but this is largely offset by the duplication of parts and labor, which simplifies and hastens the construction.

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[1] Since the writing of this paper it has been learned that there is a land dock at Pola which will take the sections of this floating dock, and there is no intention of self-docking this particular dock.

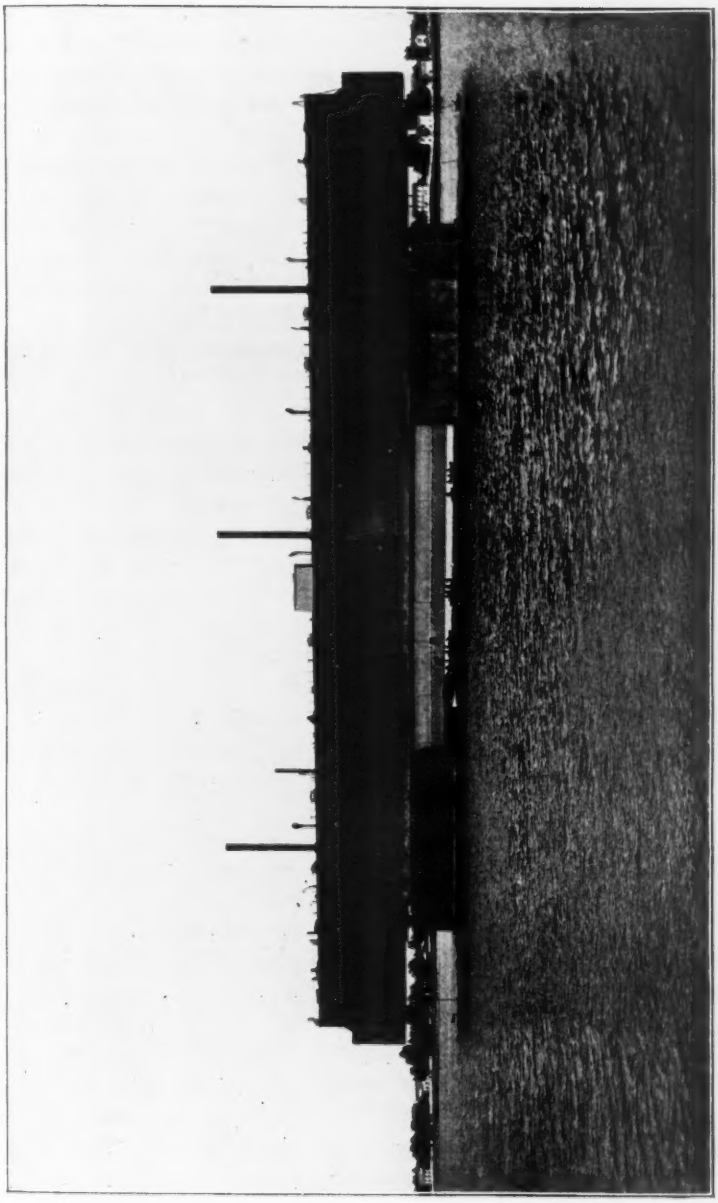

PLATE 2.—U. S. FLOATING DOCK "DEWEY," WITH CENTRAL PONTOON SELF-DOCKED ON THE END PONTOONS

The last floating dock design that has been produced is that of the Maryland Steel Company, by Mr. Henrik Hansson, one of the assistant engineers. This design was produced to meet the rigid and extensive requirements of the Bureau of Yards and Docks' specification for the government dock in the Philippines, the most exacting specification for floating docks that has so far been issued. The design was accepted and the dock built by the Maryland Steel Company.

The dock is illustrated on Diagram 9. Figure 1 is a side elevation. Figure 2 is an end elevation. Figure 3 is a plan. Figure 4 is a side elevation of the middle section self-docked. Figure 5 is an end elevation of the middle section self-docked. Figure 6 is a plan of the end sections self-docked. Figure 7 is an end elevation of an end section self-docked.

In the Maryland Steel Company dock great continuity has been secured. The side walls are continuous, and the long central pontoon is built solidly into them. The only break is in the short end pontoons, which form about one-fifth of the floor at each end, and the connections of these to the side walls and main pontoon are extensive and rigid. The low side walls on the end pontoons come into action only in self-docking, being ordinarily allowed to fill with water, and are again emptied automatically as the dock sinks and rises. These low side walls contain a pumping plant of sufficient capacity to operate the end pontoon, which is supplied with steam from a main boiler by a flexible connection. Ordinarily the small pumping plant in the low side wall is inoperative, the piping system of the end pontoon being connected to the main drainage system by a joint like that previously shown with the Cunningham dock.

In operation this dock has proved very rigid and reliable and easily operated. The self-docking has proven to be the easiest, simplest, and most quickly accomplished of any yet tried.

After this dock passes a certain length the width must also be increased in order to allow the end pontoons to be docked on the main portion.

In designing a floating dry dock the first matters receiving consideration are the clear width between side walls, the draught over keel blocks, and the length. For a commercial dock the maximum ship entering the port does not receive consideration, but rather a ship somewhat above the average, as it is the average ship that brings the largest and most profitable business to the dock. Ships below the

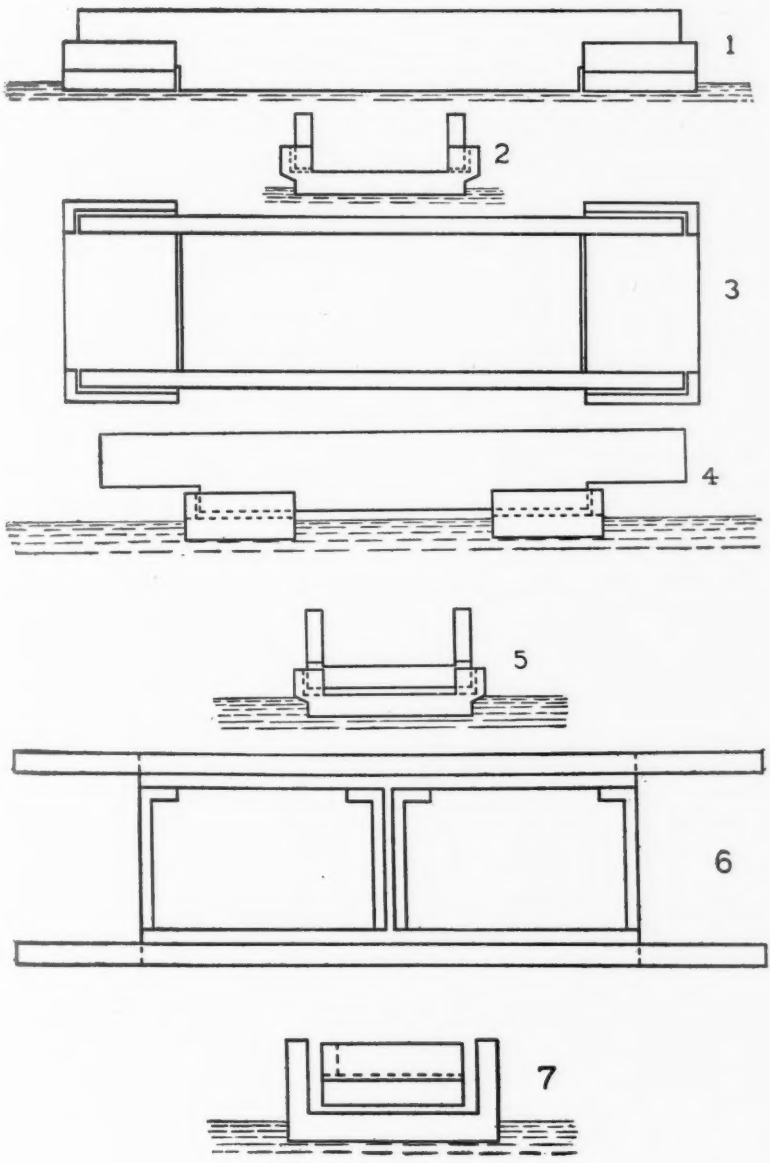

DIAGRAM 9. — THE "DEWEY"

average are, of course, readily handled by the dock, but the nearer it is worked up to its full capacity the greater will be the profit in the investment.

The determination of what will be the average ship during the life of the dock is a matter which requires careful consideration and study. Ships prefer to visit ports where there are docking facilities, and a large dock may invite larger ships than before cared to come. In any event, a large dock gives a port a favorable name among shipping interests. The coming growth in the size of ships in the future cannot always be predicted by the past, and as a general rule it may be said that it is more often the case that docks are designed too small rather than too large.

With military docks the case is somewhat different. Both the heaviest and longest vessels of a navy must be docked, and the heaviest and longest vessels likely to be built within a certain period are more easily predicted. At the same time liberal estimates should be the rule, for one warship that cannot be docked at home may place a navy in a serious predicament.

The clear width between side walls of a floating dock is not difficult to decide upon. It so happens that structural reasons have limited the maximum width of entrances to land dry docks throughout the world to 80 feet, and so by taking this dimension any ship now existing can be got into a floating dock, and for the average widths there will be a fair clearance for working space. This width is also desirable for general lateral stability of the dock. In the case of the United States government floating dry docks, the standard clear width between side walls is 100 feet. It is interesting to note that the maximum width of dry dock entrances throughout the world is one of the limiting factors of ship development.

The draught of water over the keel blocks must, of course, accommodate the normal draught of the maximum ship for which the dock is designed. In addition to this, provision should also be made for abnormal draught due to accident, and as a rule it is a wise proceeding to provide for the greatest draught of ship that is likely to be able to enter the port during the life of the dock. In military docks a deep draught over the keel blocks is of especial importance, as these docks are more likely than others to be called upon to handle disabled ships at an abnormal draught.

The length of a dock and its lifting capacity are two functions so

PLATE 3. — U. S. FLOATING DOCK "DEWEY," WITH END PONTOONS SELF-DOCKED ON THE CENTRAL PONTOON

closely related that they are best treated together, and the matter is most comprehensively considered in the case of a military dock. The military dock is called upon to deal with short battleships, long cruisers, and perhaps, in times of war, with still longer merchant ships that have been converted into naval auxiliaries. Full bearing length must

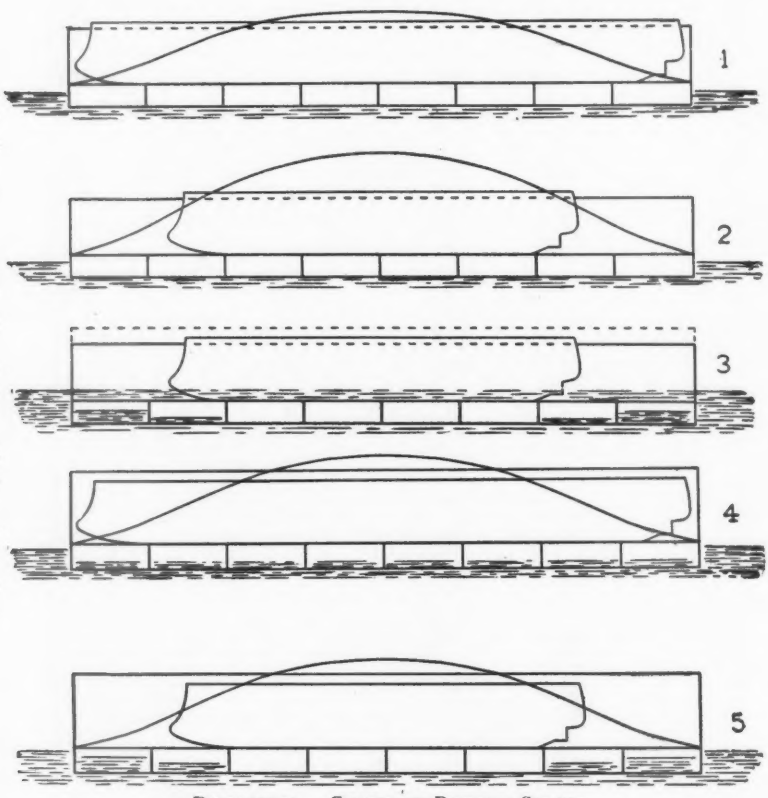

DIAGRAM 10.—CURVES OF BENDING STRAIN

be provided for the longest ship, and in addition a working platform is desirable under the ends of the ship that do not require bearing. This bearing length and working platform consist of the pontoons of the dock which give the lifting power, and there is a natural desire to utilize, so far as may be safely done, their entire displacement for lifting purposes.

The conditions to be met in the question of the length and lifting power of a floating dock are illustrated on Diagram 10, in which it is to be understood that the figures are diagrammatic only and for the purpose of illustration. In Figures 1 and 2 the docks are identical and the ships of the same weight, but of different bearing lengths. The dock has been designed just to lift the longer ship with all pontoons pumped empty. The bending strains for which the dock is designed under these conditions are the ordinates of the curve. Now to lift the short ship the pontoons must again all be pumped empty, but the upward leverage of the pontoons which are unopposed by the ship will greatly increase the bending stress and cause the curve to rise, perhaps to a point indicating danger or failure of material. The bending strains may be reduced by leaving water in the end pontoons, as in Figure 3, but under the conditions assumed the ship will not then come entirely out of the water. If the docks in Figures 1 and 2 are to have the same lifting capacity and are to lift both the long and short ships, there remains but one thing to do, and that is to increase the girder strength by raising the side walls, as shown by the dotted lines in Figure 3. In actual practice a compromise will give the best results, the side walls being raised somewhat to increase the girder strength and the pontoons deepened to give some excess of lifting capacity. In this compromise the condition of pumping and flotation are shown in Figures 4 and 5, and the bending strains are practically the same in both cases. This compromise necessitates skillful and intelligent pumping with short, heavy ships until the weight of the ship becomes less than the lifting capacity of the pontoons directly under it, after which pumping may proceed uniformly all over the dock without danger.

The United States government has been the first to refuse this compromise in the military dock for the Philippines, previously described. In that dock uniform pumping without undue strain is required for any load that it is possible for the dock to take. This would not be an economical requirement for a commercial dock, but in a military dock it insures many desirable qualities. It permits the most rapid lifting under all possible conditions. It is a safeguard against all careless and ignorant pumping which might be possible in emergency conditions. It makes it possible to hog or sag a ship on the dock for special repairs. It makes it possible to dock a ship near the end of the dock and also to dock it on an incline.

The general stability of a floating dock varies directly as the square

of the number of water-tight divisions. This is illustrated in Diagram 11. Figures 1 and 2 are cross sections of pontoons, having two and four water-tight compartments, respectively. The comparative stability of these as affected by the shifting of water ballast due to heeling is four to sixteen. The desirable longitudinal girders in a floating dry dock, shown in Figure 3, make six lateral compartments possible in connection with the structural design, so that in practice the shifting of water ballast from heeling is quite small.

The stability of a dock under various conditions in lifting a ship and in self-docking its own parts is an important matter. In the lifting of

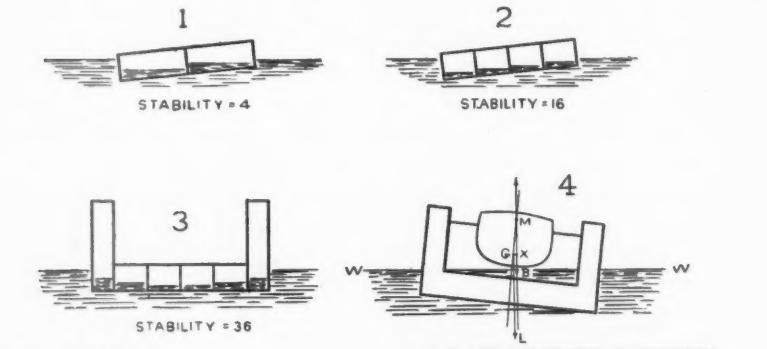

DIAGRAM 11.—CORRELATION BETWEEN STABILITY AND NUMBER OF WATER-TIGHT DIVISIONS

a ship the case is shown in Diagram 11, Figure 4. In this figure it is apparent, and it is confirmed by calculation, that the stability is the least with the water plane between the bottom of the ship's keel and the deck of the pontoons, for in this position the ship's buoyancy has entirely left the combination, the buoyancy of the pontoons themselves has not yet come into play, and the comparatively slight buoyancy of the side walls is all there is to resist overturning. The stability of the combined ship and dock at this particular period may be largely controlled by the pumping in a dock where but little shifting of water ballast is possible, for the more nearly the dock is kept level the greater the metacentric height. With a well-designed floating dock it is an

easy matter so to conduct the pumping that the dock will never be more than from 6 inches to 1 foot out of level, and under no circumstances is it necessary that the dock should be more than 2 feet out of level in raising a ship. Two feet out of level, however, is only about 1° with a fair-sized dock, and may be taken for the possible list in considering stability. Using 1° as the possible list of the dock after the ship is entirely out of the water and before the pontoon decks have come above the surface of the water in sufficiently numerous calculations has shown that the metacentric height for this position of least stability will vary from 5 feet to 20 feet, according to the cross section of the combination of ship and dock. In comparison with the metacentric height of a ship that may be from 1 to 3 feet with the same degree of heel, the great stability of a floating dock under the worst condition is at once apparent. The stability of a floating dock of approximately standard cross section and design is so well assured that the calculations are more a matter of interest than necessity.

Apparently the most unstable position of self-docking shown in the preceding diagrams is that of the main portion of the Maryland Steel Company dock; but even in this at the plane of least stability the metacentric height is 17.82 feet.

The next matter for consideration is the deflection of a floating dry dock under the various loads and conditions. The longitudinal deflection under the maximum loads is a matter which gives more concern to designers than any other consideration. It is the governing factor in the relation of length to total lifting power, height of side walls, and total amount of material entering into the structure. The earlier floating docks had to deal with comparatively short ships of considerable inherent stiffness, but the modern floating dock, and especially the military dock, has to deal with ships both long and short, having great weight unevenly distributed and considerable flexibility when not water borne. Some designers have prided themselves on the small weight of their docks compared to the total lifting power, frequently getting the structural weight of the dock less than 40 per cent. of its total displacement capacity. Such docks will always give a large deflection, and as they deteriorate from age may become a menace to themselves and the ship they carry when worked up to their apparent capacity.

Under the possible load which a dock can lift, which is determined by its displacement, there is certain to be deflection, as the dock is

built of elastic material and supported by a liquid medium. This greatest possible deflection should be confined within safe limits, both for the ship and dock.

Having determined and limited the greatest possible deflection, the deflections of the dock at its rated capacity must be established.

Until recent years dock designers have been largely satisfied with safely lifting a ship and returning it to the water uninjured, and as long as this was the ruling condition there could be no marked advance in floating docks.

The United States government, in its new floating dock for the Philippines, has inaugurated a new deflection requirement that marks a decided and important advance in this line.

The deflection of the dock is limited to a small amount under the full rated capacity, with the dock pumped uniformly all over.

The full effect of limited deflection under uniform pumping is best shown by a comparison. In the government dock at New Orleans uniform pumping was not specified; the dock is 525 feet long, has a rated capacity of 15,000 tons, a displacement of 18,000 tons, and a total weight of about 6,000 tons. The new Philippine dock, in which uniform pumping was specified, is 500 feet long, has a rated capacity of 16,000 tons, a displacement of 22,000 tons, and a total weight of about 11,000 tons; when pumped in the manner allowed for the New Orleans dock it will dock a 20,000 ton battleship with only slight deflection. (Limiting the deflection under uniform pumping has, therefore, about doubled the strength of the Philippine dock as compared with the New Orleans dock.)

Some of the reasons for uniform pumping in a military dock have already been given. Other reasons are that a dock so designed can be water ballasted until the deflection under the rated load is all removed and the ship brought to a straight keel or even hogged. Repairs and changes can then be made under the same conditions as when a ship was built, the structural advantages of which are great.

This liberality of design which is desirable in a military dock may not always be expedient in a commercial dock, but in any event the deflection should be kept within the safe limits of the elasticity of any hull which it is possible for the dock to lift.

On account of the shorter span and the necessary uniform pumping athwartship, the transverse deflections in a dock are more easily dealt with, but they should always be calculated and limited without esti-

mating on the use of shores from the side walls of the dock to the ship.

The dimensions and capacity of a floating dry dock having been determined and its structural strength decided, there remains to be selected the method of self-docking that will best suit these conditions.

The preservation of a large floating dry dock is of so much importance that there is sometimes a tendency to give the self-docking feature an ascendency over the regular functions and purposes of the dock.

In general, the following principles should govern the self-docking features of a floating dry dock: Great continuity in docking operations; smallest possible number of divisions and auxiliaries; joints at greatest possible distances from points of greatest strain; joints always dry and accessible; simple and easily understood method; remoteness or impossibility of accident in self-docking; largest possible stability and strength when self-docked; quickness of self-docking and reassembling.

DIAGRAM 12.—DOCKS WITH CAISSON

Many of these desirable features are antagonistic, and how well they have been met, coördinated, and reconciled up to the present time can be seen by a study and comparison of the types previously presented. These types, it is believed, represent the best of every class that has been devised, and under them there are many unimportant and mostly valueless variations.

The quickness of self-docking is a most important matter in any dock, but especially so in a busy and prosperous commercial dock. If self-docking is long, complicated, or liable to give trouble, it will never be attempted until absolutely necessary, and in the meantime the under-water portion of the dock structure may have suffered much deterioration.

The best record yet made in self-docking is that of the new government dry dock for the Philippines, which was self-docked and reassembled on the first trial in fourteen days. It is believed that on a subsequent trial this time could be reduced to ten days.

This does not take into account any extensive cleaning or painting that might be desirable, and to completely clean and paint the submerged portions of an extensive floating dock would, under the most favorable conditions, require from one to three months.

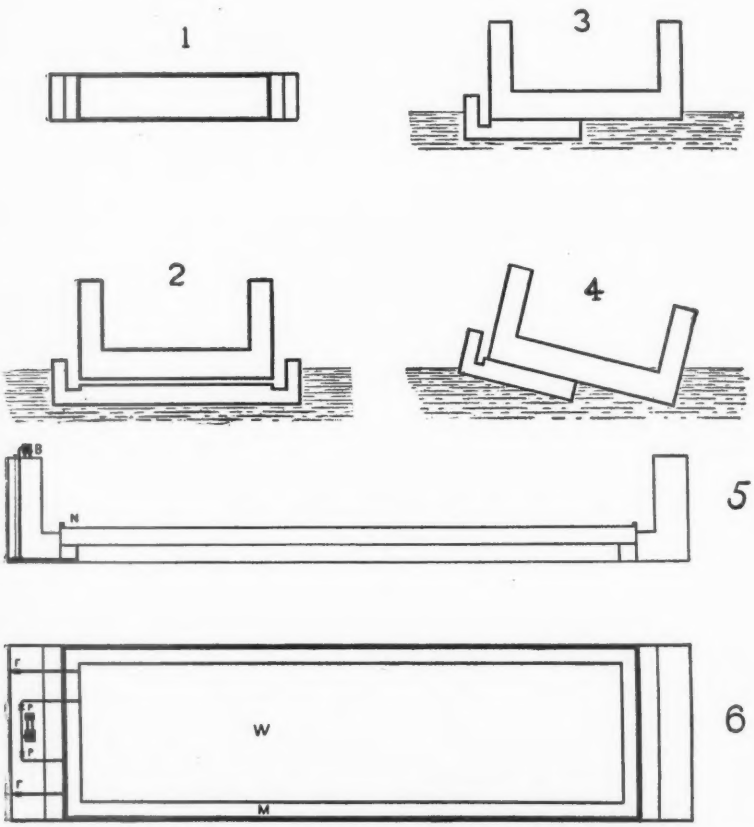

DIAGRAM 13. — THE NEW CUNNINGHAM CAISSON
B, pump; *F*, flushing valve; *M*, flotation chamber; *N*, packing ring; *P*, pump valves; *W*, working chamber

The more experience that is gained with self-docking docks, the more desirable does a return to the original solid type appear. To this end an adaptation of the ship caisson has been proposed in this country, and is understood to have been tried unsuccessfully in Europe. The application is illustrated in Diagram 12. Figure 1 is an end view of a

dock with a caisson extending entirely across the bottom and up both sides above the water line. Figure 2 is an end view of a dock with a caisson extending just past the centre and up one side. These caissons are entirely open on the sides next the dock. The proposition is to make them water-tight against the dock, and then pump out the contained water, so that the submerged portions of the dock will become accessible. The difficulties to be encountered with these caissons are evident. In Figure 1 it would be a mechanical impossibility to make a water-tight joint on both sides at once, and the sag would leave more or less opening at the bottom. In Figure 2 there would be much difficulty in controlling the caisson, and the end under the dock could not be got up sufficiently tight against the dock to make pumping effective. I have recently proposed a caisson, which is here generally announced for the first time, which has worked satisfactorily in a scale model and which may possibly solve this problem. The caisson is illustrated in Diagram 13. Figure 1 is a plan of the caisson. Figure 2 is an end view of a dock with a caisson extending entirely across before lifting against the bottom. Figure 3 is an end view of a dock with a short caisson sealed against the bottom. Figure 5 is a sectional elevation, and Figure 6 a sectional plan of the caisson, showing the general arrangement.

The action of this caisson is as follows: Water is admitted to the main chamber freely until the combination is sunk as far as the displacement of the supplemental chamber will permit, which is less than submergence. Water is then carefully admitted to the supplemental chamber until the combination just loses its buoyancy. The caisson then sinks until arrested by the floats attached to the entrance shafts, and is then ready to move into position under the dock. In the case of the short caisson an approximate level is maintained by counterbalancing the caisson chamber. Being in the desired position, the water is exhausted from the supplemental chamber and the caisson rises and seals against the bottom of the dock, after which the main chamber can be pumped dry, giving access to the bottom of the dock. The manner of gaining access to the edges of the dock is shown in Figure 4. The caisson is sealed against the bottom of the dock, with the end projecting; the edge of the dock and the projecting end of the caisson are then canted out of water, after which the main caisson chamber can be pumped dry.

The successful application of the caisson to the bottom of a floating

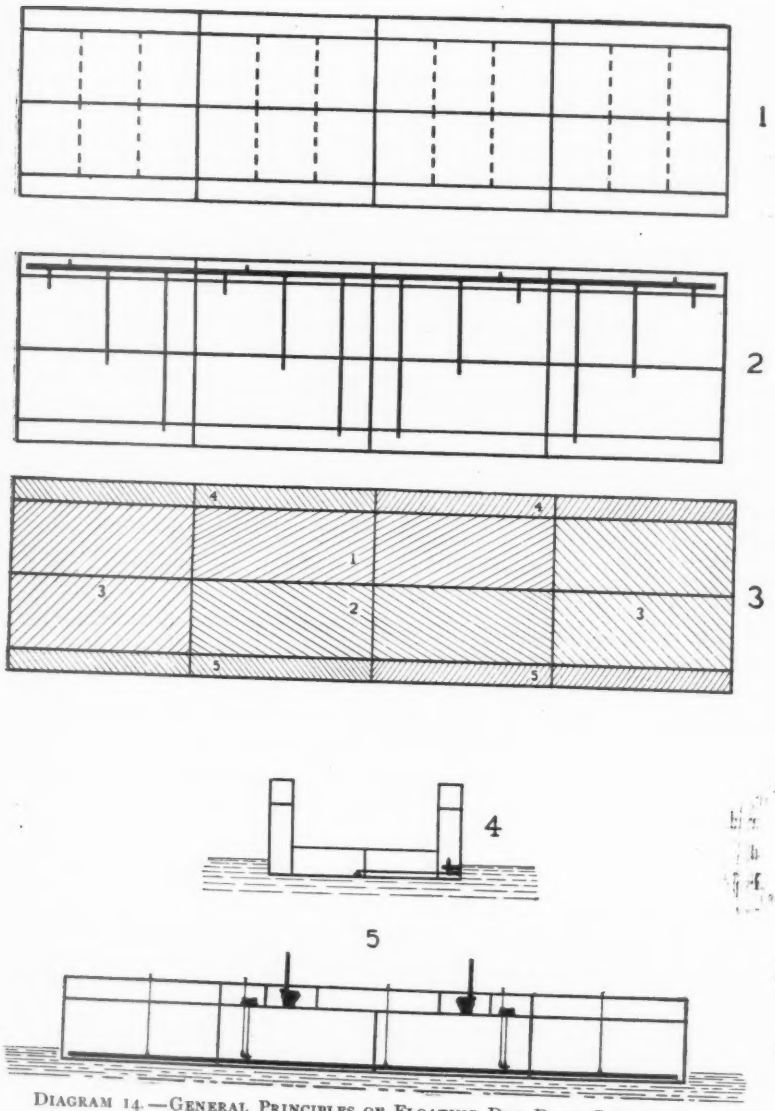

DIAGRAM 14.—GENERAL PRINCIPLES OF FLOATING DRY DOCK CONSTRUCTION

dry dock will permit a return to the solid type to which all self-docking docks strive to approximate. It will further permit of the painting or repair of the bottom of the dock at the same time that a ship is undergoing repairs in the dock; and the only time that the dock cannot be in use is when working on the edges. In the solid dock the construction will not only be strengthened and simplified, but the pumping system as well will be much more simple and easily arranged.

The general principles on which all floating dry docks are constructed are illustrated in Diagram 14. Figure 1 is a plan view of the pontoon or body of the dock, with the lines of girders. The solid lines are water-tight bulkheads, and the dotted lines are open bulkheads, or trusses. Figure 2 is a plan view showing the water-tight compartments alone and the piping leading into them from the pumping main in the side wall. There may be a pumping main in each side wall, but it is considered better practice to have it only on one side, as the pumping is then more directly under the observation and control of the dock master. Each pipe is controlled by a quick-acting wedge valve. For the easier regulation of the pumping, the balancing of the dock, and the application of the lifting power in the correct manner the water-tight compartments are collected into groups, as shown in Plan 3. The valves of all the pipes leading into a group are coupled to one valve rod, so that all are opened or shut together. All the valve rods are brought to one station by a system of bell crank levers, and at this station the dock master regulates the entire pumping of the dock. Figure 4 is an end elevation of the dock, showing the longitudinal lines of water-tight bulkheads. The pumping main, with pump located on top, and discharge outboard are shown, and also the flooding inlets and the lead of a pipe to a compartment.

Figure 5 is a side elevation of the dock, showing the framing and bulkheads in the side walls, the engine deck with engines and boilers, and the pumping main with its pumps and flooding inlets. Three pumping units are the least that should be installed on a large floating dock in order to secure a fairly uniform flow of water from all compartments and to provide against serious disablement in case of any breakdown. (In the case of a commercial dock whose location is fixed, the pumps may be operated to advantage by motors supplied with power from a station on shore.)

In docking a ship the following method of pumping will always be correct, whether the dock is designed for uniform pumping or not. The ship having been centred, pump uniformly until the ship is seated

firmly, it making little difference whether the blocks are taken at the bow or stern first; if there is any preference it is usually the bow. After the ship is seated pump from the centre of the dock first, gradually extending the pumping towards the ends in the order indicated by the numbers in Figure 3, Diagram 14. The pumping of the side walls is held back to secure quick balancing, and incidentally for priming the pumps if the pumping is temporarily stopped towards the last stages. Only slight regulation of valves is necessary to keep the dock level

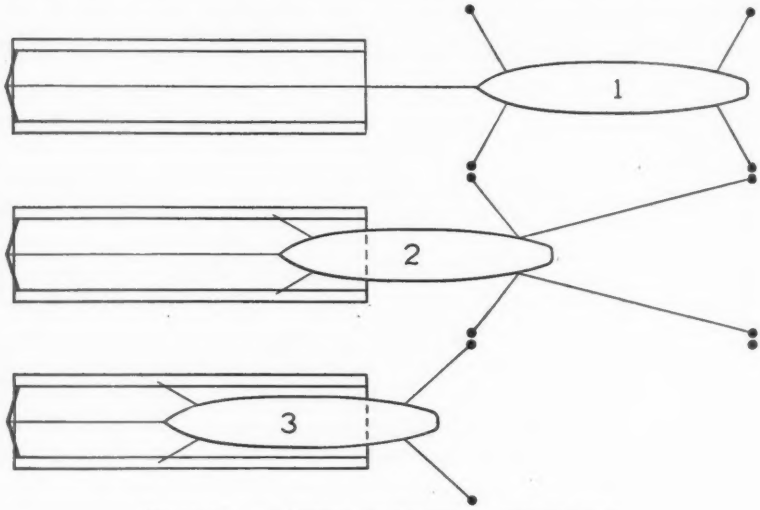

DIAGRAM 15. — METHOD OF PLACING A SHIP IN DOCK

where the arrangement of groups is correct and where there is an ample flow of water through the pipes.

The side wall decks of a dock should be fully equipped with capstans, fairleads, and bitts. A bridge at the forward end for a headline is desirable, but not absolutely necessary. With four moorings at the entrance of a dock, it is entirely possible to take a ship in without the use of tugs. On Diagram 15 is shown the placing of a ship in dock. Figure 1 is the ship held by the buoys and with a headline out. Figure 2 shows the ship about one-third entered and the lead of the lines at that time. Figure 3 shows the ship three-quarters entered and the lead of the lines. Leaving the dock is easier than entering it, for as soon as the ship's stern is clear she may be started astern and clear the dock very quickly.

The government requires that the pontoon decks of its docks shall be made sufficiently strong to take blocking at any point; so far this has not been generally the case with commercial docks, but it is a valuable property and deserving of consideration for all docks. The arrangement of blocking on a government dock is shown on Diagram 16. Figure 1 is a plan and Figure 2 an end elevation. Shores may also be used from the stages on the side walls.

The limited width of the entrances to land dry docks and its effect on the development of ships have been referred to. The depth of water over the sill of land dry docks is another limiting factor of ship development; and when it is considered that from five to eight years are

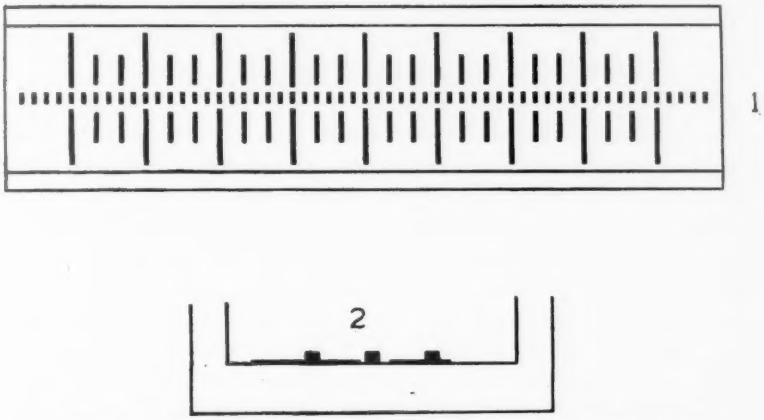

Diagram 16. — Arrangement of Blocking on a Government Dock

required for the construction of a land dry dock, it would seem as if any general increase in the size of ships had nearly reached the limit at the present time. Should any radical development in ship design be determined on, the immediate relief will be found in the floating dock, for it can be constructed of any dimensions and capacity desired in less time than a ship can be built, and it can be towed to any location desired.

The extent of this paper only permits of the treatment of the most general and important principles of floating dry docks. While the details are both important and interesting, a general and comprehensive understanding of the subject is the best foundation for those who desire to go farther into the question.

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE STERILIZATION OF SEWAGE-FILTER EFFLUENTS

BY EARLE B. PHELPS AND WILLIAM T. CARPENTER

THE DESIRABILITY OF STERILIZATION

THE primary purpose of sewage purification is the protection of the purity of the streams. The Lawrence experiments first showed that, by means of sand filters, sewage could be purified to an extent which is for all practical purposes complete. This means that practically all the organic matter and the living bacteria of the sewage are either removed or converted into harmless mineral constituents. Such a degree of purification is possible, but it involves the use of such large areas of suitable sandy land that, except under the most favorable circumstances, its cost to a city of moderate size is practically prohibitive. Consequently the tendency for the past decade has been toward more rapid processes of purification; that is, processes requiring smaller areas of land for the treatment of given volumes of sewage. The results of experiments along this line, carried on in many parts of the world, are now well known. We have seen the successive development of the septic tank, the contact filter, and the trickling filter, each of which has resulted in an increase in the possible rate of treatment, until the original maximum rate of fifty or sixty thousand gallons per acre per day has been multiplied fifty fold or more. This great saving in filter area has not been obtained without some sacrifice. With the progressive increase in the rate of treatment there has come a more or less progressive deterioration in the quality of the effluent, so that the effluent of a modern trickling filter, so far as appearance goes, and indeed often in its chemical analysis, seems to be little better than the crude

sewage. But there is one essential difference. In passing through the filter the sewage has been robbed of its putrescibility, that is, of its tendency to undergo offensive putrefactive fermentation. The organic matter of the sewage is unstable, or liable to putrefy, while that of the effluent is stable. And we have learned that in bringing about this one change in the character of the organic matter we have accomplished the most essential thing in sewage purification, as will be seen if we analyze a little more in detail the effects of stream pollution. These may be conveniently considered under three heads — æsthetic, economic, and sanitary.

The discharge of a relatively small amount of sewage into a stream brings about no serious physical conditions. As the amount of sewage increases year by year, however, there is ever increasing evidence of its presence. The waters become discolored, a greasy scum appears on the surface, and, worst of all, the black mud deposited upon the bottom ferments, giving rise to malodorous gases. Finally, if the sewage be added in still greater amounts a point is reached, quite suddenly, at which the balance swings, and the stream becomes permanently black and offensive and will no longer support fish or other life. It has, in fact, changed from a polluted river to a sewer. There may be no thought of using this stream for domestic purposes, and there may even be no serious monetary damage involved, but there can be no more potent argument for sewage purification than such a ceaseless offence to the eyes and nostrils of the community. It is now a recognized fact that to prevent such conditions as these it is not necessary to free an effluent from organic matter, much less from bacteria, but that it is alone sufficient to render it thoroughly stable.

There are also certain definite economic damages caused by stream pollution. Communities are ofttimes under the necessity of using for sources of domestic water supply the waters of polluted streams. Still more frequently such sources are much more available than a more distant unpolluted source, and it is found to be more economical to filter the polluted water than to bring in the more distant one. No contention can be made that streams should be so far protected that they may be used directly for public water supplies. In the very nature of the case, streams flowing through populated regions are polluted, and the complete purification of the cities' sewage would still leave countless small but significant sources of possible infection. Therefore, the contention that it is not the duty of the sewage works

to turn out a potable water seems reasonable. All ends are served most fairly and most economically by placing upon the water filter the burden of producing an unpolluted water for domestic use. It must be obvious, however, that the condition of gross physical nuisance described above as an open sewer rather than a polluted river must render it impractical, if not impossible, to treat such a water upon a water filter in the ordinary manner. It is equally true, though less obvious, that any considerable pollution of a stream by putrescible organic matter increases the work of the water filter and, in consequence, reduces its factor of safety and efficiency in the removal of disease germs. This contention will become more obvious if we bear in mind the fact that putrescible organic matter is matter requiring oxygen to render it stable, and that the work of the water filter is simply the oxidation of all such matter, together with the organic matter of the living bacteria and other organized animal and vegetable forms. To offset, therefore, this increased pollution lower rates of filtration and larger areas are necessary, with consequent increased expense for construction and maintenance.

Among other financial losses it is sufficient to mention the harm done to profitable fishing, decreased value of the water for industrial purposes, depreciated land values, and other monetary losses due to causes described as æsthetic.

In any equitable solution of the problem we must seek the middle ground, and carefully balance the cost of purifying sewage to any given degree of purity against the saving in filter area and maintenance thereby made possible on the water plant, and against other economic advantages. Experience has shown that non-putrescible effluents can be obtained from sewage filters run at feasible rates, and that the discharge of such effluents, if reasonably free from suspended matter, will throw little or no additional burden upon the water filter; that raw sewage or putrescible effluents reduce the power of the stream to maintain its own normal character and render its subsequent purification more difficult; and that the benefits of any more complete purification of the sewage beyond the point of perfect stability will be entirely incommensurate with their cost. Therefore the economic as well as the æsthetic arguments for the purification of sewage are met by such a treatment as will produce non-putrefactive effluents.

Sanitary considerations are themselves economic in their ultimate

analyses, but there are certain aspects of the present subject which are, primarily, sanitary. The relation of sewage disposal to water filtration has already been commented upon. In the discussion of the economic phase of this relation it was assumed that satisfactory purification of the water would be obtained at whatever cost. Where polluted waters are being taken directly into the city mains the question is naturally a serious sanitary one, but again it must be asserted that the responsibility rests upon that community using the water. The most efficient purification of the sewage before discharge will never make a water safe which drains a populated country. The sewage can and should be rendered non-putrescible, but it will still be germ-laden. The removal of these residual germs, together with those others which by scores of devious and hidden paths have found their way into the stream, must depend upon the water works authorities. The case is aptly put by that dictum ascribed to Mr. Hering: "Nothing to be discharged into a stream without purification; nothing to be taken from a stream without purification." The greatest good to the greatest number finds its solution in this system of dual responsibility.

Sewage disposal has, therefore, curiously enough come to be less and less a matter of sanitation. As the practice has gradually developed from the slow sand filter toward rapid, coarse-grained filters, it has become more obvious that the removal of bacteria is not one of the functions of a sewage filter. There is, as a rule, a removal of a portion of these organisms. Whether or not there is a satisfactory elimination of the dangerous germs of disease is a point upon which there is great diversity of opinion and very little exact knowledge.

It was seriously feared at one time that pathogenic germs might multiply in the septic tank. Woodhead made physiological tests of crude sewage and septic tank effluent, and concluded that there were no organisms in the latter capable of setting up morbid changes in animals after inoculation. Rideal states that "satisfactory evidence in most of the systems is now available, from which I think we are justified in concluding that, even if towns on a river like the Thames adopted bacterial schemes, the pathogenicity of the London water supply would not be adversely affected." (Great Britain, 1902, A, Quest. 4148.)

On the other hand, Houston, acting for the Royal Sewage Commission, made a careful bacteriological study of the whole problem. He concludes that:

The effluents from septic tanks, intermittent contact beds, continuous filtration beds, etc., contain an enormous number of bacteria. In some cases the percentage reduction of microbes in effluent as compared with raw sewage is striking; but as an effluent must be judged by the actual state it is in, and as the number of microörganisms still remaining is almost always very large, percentage purification would seem to be of minor importance. In not a few cases the bacteria are practically as numerous in the effluent as in the raw sewage.

The different kinds of bacteria and their relative abundance appear to be very much the same in the effluents as in the crude sewage. Thus, as regards undesirable bacteria, the effluents frequently contain nearly as many *B. coli*, proteus-like germs, spores of *B. enteritidis sporogenes* and streptococci, as crude sewage. In no case, seemingly, has the reduction of these objectionable bacteria been so marked as to be very material from the point of view of the epidemiologist. No definite proof has been furnished that the effluents from bacteria beds are conspicuously more safe in this sense in their possible relation to disease than is crude sewage. Indeed, all the available evidence tends to show that they must be regarded as nearly if not quite as dangerous to health as raw sewage. In this connection we would again take note of the streptococcus test. If it be true that streptococci are more delicate germs than the typhoid bacillus, their presence in any number in the effluent would seem to indicate the possibility or probability of the enteric fever bacillus also surviving under similar conditions, and, in general, would lead us to infer that the biological processes at work were not strongly inimical, if hostile at all, to the vitality of germs of pathogenic sort. (Great Britain, 1902, B, p. 26.)

At the Sewage Experiment Station of the Massachusetts Institute of Technology, bacteriological examination of crude sewage and of the effluents of four septic tanks and fifteen filters were made during the summer season. The following average results were reported by Winslow (1904):

Sample.	Number of Examinations.	Bacteria per Cubic Centimeter.					
		Lactose gelatin at 20° C.			Lactose agar at 37° C.		Anaërobic agar.
		Liquefiers.	Acid formers.	Total.	Acid formers.	Total.	
Sewage	56	365,000	1,670,000	5,430,000	1,670,000	3,760,000	2,440,000
Septic effluent . . .	56	162,000	495,000	1,750,000	650,000	1,040,000	930,000
Contact filters . . .	140	60,000	270,000	1,060,000	290,000	570,000	440,000
Trickling filters . .	18	134,000	114,000	451,000	284,000	1,170,000	200,000
Sand filters	15	500	1,360	9,160	11,400	43,600	1,200

There were four septic tanks running at storage periods of from twelve to forty hours, nine contact filters differing in material, depth, and rate, three trickling filters, and three sand filters, each set running with crude and two kinds of septic sewage.

The septic tank and two trickling filters now in operation at this station gave the following bacterial results, the figures being averages of the results of almost daily examination during the past summer.

	Bacteria per c.c. Lactose agar at 37°.	B. coli. Positive * tests in $\frac{1}{100000}$ c.c.
Sewage	1,300,000	65 per cent.
Trickling filter receiving sewage	750,000	35 per cent.
Septic effluent	1,650,000	66 per cent.
Trickling filter receiving septic effluent	750,000	35 per cent.

* The bile broth presumptive test, recommended by Jackson (1906), was employed.

About one-half the total organisms were removed by filtration, and the reduction of *B. coli* was practically in the same proportion. Such results as these would seem to justify fully the statement quoted from Houston.

We are still ignorant of the fate of the dangerous pathogenic organisms, so far as any direct experimental knowledge goes. In the absence of such knowledge it is only reasonable and safe to assume that such organisms do, in part, at least, pass through the filter.

We must therefore conclude that sewage purification by modern processes can be made to produce effluents which are reasonably clear and stable, but which are still germ-laden and, potentially, infectious; that the discharge of such effluents into streams or tidal waters will not bring about physical nuisance or economic damage; and that, so far as the use of water for domestic and industrial purposes is concerned, such discharge is just and reasonable.

At the present time, however, we are confronted with a consideration which promises to add a new chapter to the history of sewage purification. This is the question of the relation of sewage pollution and sewage disposal to the shellfish industry. Many of the oyster and clam beds of our eastern seaboard are seriously polluted with sewage. Both at home and abroad this subject has reached the magnitude of a "scare," and a serious falling off in the demand for these shellfish is reported. In this country, at least, most of this pollution is due to

the discharge of untreated sewage into the rivers and tidal waters. In Great Britain it is more commonly the result of the discharge of partially purified effluents which are quite stable, as we have described them, but germ-laden. In many places the matter is being studied or agitated. In Great Britain the Royal Sewage Commission has issued a voluminous and valuable report upon the pollution of shellfish (Great Britain, 1904). In our own country the Massachusetts State Board of Health has had the question under investigation for several years, and has just issued a valuable report bearing upon the subject (Massachusetts, 1906); New York State has a Harbor Pollution Commission which for two years has studied conditions in New York Harbor; New Jersey is alive to the danger which threatens one of her great industries; and Baltimore is taking active steps to improve the sanitary conditions of upper Chesapeake Bay. The difficulties of the situation are obvious. A polluted river water may be rendered potable through filtration, but purification of shellfish seems to be out of the question. It follows, then, that the bacteria of sewage must not be discharged upon shellfish beds. The kind of purification which we have discussed will no longer serve, for sanitary considerations are here paramount. A higher standard of purity — a bacterial purity as well as an organic stability — must be demanded in such cases, or else the taking of shellfish must be prohibited. When the community is large and the shellfish industry small this latter alternative will probably prove the more satisfactory. Where small communities are polluting large and important beds, thorough purification by sand filters is not an unreasonable requirement. Unfortunately, the greatest shellfish areas of the country are so situated that they are subject directly or indirectly to possible pollution from concentrated populations.

In a carefully prepared paper on this subject by Mr. G. W. Fuller (1905) it is stated that the annual crop of oysters gathered along the Atlantic and Gulf coasts in 1902 amounted to over twenty-five million bushels, valued at over thirteen million dollars, and that the crop of clams was over two million bushels, valued at two million dollars. Over one-half of this total product came from the three states of New Jersey, Maryland, and Virginia, and were, in the main, grown in the waters of the Delaware and Chesapeake Bays, into which the sewage of Philadelphia, Wilmington, Baltimore, Washington, and other cities is discharged. At present, owing to the tremendous dilution of the polluting matters in these bays, the danger of pollution is

in most cases remote, but it is significant, ever present, and ever increasing. The great value of the industry and the even slight danger to which it is now exposed has called for action on the part of those most interested. In Baltimore a system of sewerage and sewage disposal is being planned by which it is intended to remedy the present serious pollution of the Patapsco. In calling upon a commission of experts for advice, the Sewerage Commission of Baltimore distinctly specified "that the effluent proposed to be discharged into Chesapeake Bay or its tributaries in the system to be recommended by the engineers shall be of the highest degree of purity." By a coöperative arrangement between the states of New Jersey and Pennsylvania the condition of the Delaware River is being investigated, and measures will be considered by which the present serious pollution of that river shall be remedied.

It seems that in such cases the value of the industry, together with the difficulty of protecting the beds in any other way, will ultimately force upon the authorities one of two alternatives: complete purification by filtration through sand, or rapid and partial purification by means of contact beds or trickling filters, followed by some kind of sterilization.

The former is practically what has been recommended for the city of Baltimore, although it is there proposed to make use of sand filtration as a secondary process, following treatment on trickling filters. In this way the efficiency of the sand filtration is obtained at a considerable saving in filtration area. The Board of Advisory Engineers has estimated the cost of works for the complete treatment of seventy-five million gallons of sewage per day at $3,283,250, of which sum $1,040,750, or over 31 per cent., is for the supplementary treatment on sand filters. The annual cost of operation is estimated at $115,500, of which $55,000, or 48 per cent., is for the supplementary treatment (Baltimore, 1906). This gives some idea of the price which it is necessary to pay for effluents of bacterial purity over and above the cost of rendering the sewage stable and non-putrefactive. In regard to sterilization by chemicals, the engineers report that "to remove all bacteria remaining in the settled effluent from the sprinkling filters by disinfectants, such as hypochlorite of lime or of sodium or sulphate of copper, would be prohibitively expensive"; and this opinion is based upon the best knowledge of the subject now available. The fact is, this alternative — chemical sterilization — has not yet

been reduced to its lowest terms. We have yet to learn how effective it may be made and at what cost, and what after effects, objectionable or otherwise, are likely to follow its employment.

A somewhat careful study of the question has forced the authors to the belief that there is much of value in this process, and that under certain circumstances and conditions which are common in this country, particularly where the oyster question is involved, it may be found to be the best possible solution of the whole problem.

In connection with an experimental study of certain kinds of chemical sterilization, the results of which are here presented, the literature of the subject has been thoroughly reviewed, and it is thought that a summary of our available information might prove of value. In connection with the experimental data which have been compiled, the all-important question of cost has been gone into in some detail, particularly in the case of those processes which in other respects appear to be feasible.

The Efficiency and Cost of Sterilization

In Great Britain the somewhat indefinite allusions of the Royal Sewage Commission to the question of sterilization as a finishing process in sewage treatment have aroused a storm of discussion and resulted, at least, in clearing away many misconceptions. Sterilization processes of many kinds have been investigated, and the subject has been freely discussed. For the following classification of sterilizing agents and for many of the facts here cited the writers are indebted to Rideal (1905), whose careful paper on the subject discusses its possibilities in a thoroughly impartial manner. Other authorities are cited so far as possible. Except when otherwise stated, costs are based upon present Boston prices.

The various methods proposed for the sterilization of effluents will be taken up in the following order.

1. Heat.
2. Lime.
3. Acids.
4. Ozone.
5. Chlorine and its compounds.
   - (*a*) Chlorine gas.
   - (*b*) Oxychlorides.
   - (*c*) Chloride of lime; hypochlorites.

6. Copper and its compounds.
7. Miscellaneous.
   (*a*) Permanganate.
   (*b*) "Amines."

1. HEAT. — The use of heat has been suggested for the sterilization of sewage and effluents. In his testimony before the Royal Commission, Klein (Great Britain, 1902, A, Quest. 9674) referred to a patented apparatus which he considers quite feasible, and by the use of which enough ammonia was to be recovered nearly to pay for the fuel required. There is no record that this device has ever been used on a large scale, and its claims are almost too fanciful. A rough calculation of the anthracite coal necessary to raise sewage to the boiling point from the average temperature of 60° F. gives 40 tons per million gallons, which will cost say $4 per ton, or $160. The total amount of free ammonia in a million gallons of Boston sewage is about 100 pounds, which, if concentrated to the commercial strength of 28 per cent., would bring 40 cents per pound, or $40. These are the most favorable figures possible, and in reality the revenue would be a much smaller proportion of the cost. Sterilizing by heat, therefore, will be a very expensive process and may safely be disregarded.

2. LIME. — Caustic lime acts as a weak germicide. The considerable removal of bacteria noted when lime is used as a precipitant for sewage is undoubtedly due to the action of the precipitate itself in dragging down with it the bacteria which it has entangled. Such an action is common in all precipitation, and even the sedimentation of sewage is always accompanied by a great reduction in the numbers of bacteria. For use with effluents, therefore, lime alone would not seem to be a valuable germicide. Rideal states that sixty to seventy grains (850–1,000 parts) are inefficient in sterilization. Thresh believes that lime would furnish a satisfactory sterilization of effluents, but has not tried it. (Great Britain, 1902, A, Quest. 8917.)

3. ACIDS. — Most bacteria are much more sensitive to acids than to alkalies. This applies particularly to the typhoid and cholera germs. Rideal considers it feasible to use acids as germicides. He states that Stutzer found .05 per cent. of sulphuric acid fatal to cholera in fifteen minutes and .02 per cent. fatal in twenty-four hours; that Ivanoff found that .04 per cent. to .08 per cent. destroyed the cholera germs in the sewage of Berlin and of Potsdam; and that Kitasato found .08 per cent. sulphuric acid fatal to typhoid in fifteen minutes, a result

obtained also by Rideal himself. To furnish one million gallons of sewage with .08 per cent. sulphuric acid would require 6,640 pounds of acid, at an approximate cost of $332. Smaller amounts of acid might be used, since it would not be necessary to kill typhoid germs in so short a time as fifteen minutes; but, on the other hand, there is in most sewage a considerable amount of free alkali requiring neutralization before any effect of the acid would be obtained. On the whole, this process would seem to be an impractical one except in cases of emergency. It is interesting to note that the sewage of Worcester, Massachusetts, contains normally an average of .01 per cent. free sulphuric acid, or half enough to kill cholera germs in twenty-four hours.

4. Ozone. — Ozone has been used with more or less success in various parts of Germany, particularly at Weisbaden, for the sterilization of drinking water. Although the process has been most favorably spoken of by those in immediate care of the investigations, it has not generally been regarded as a success, and its use at Weisbaden has been discontinued. There can be no doubt as to the possibility of procuring a satisfactory effluent by this process when the water in question is a highly polluted river water. Whether the process would deal satisfactorily with a sewage effluent of considerable turbidity has not been determined. Rideal points out that ozone is but sparingly soluble. Such being the case, it might altogether fail to penetrate the solid masses in the effluent, since the rate at which a dissolved gas will thus penetrate solids is a direct function of its solubility.

The principal cause of the failure of the ozone process, however, seems to be its expense. If this is the case in water works it seems hardly possible that the process could be applied to sewage effluents as an additional safeguard after purification. There are no data at hand for estimating the cost of ozone treatment when applied to effluents. Besides the cost of treatment there is the very considerable cost of installation of the necessary machinery and towers.

5. Chlorine and Its Compounds. — Chlorine is well known as a powerful germicide. It has long been known as a bleaching agent acting upon organic coloring matter, not directly, but by means of the free nascent oxygen which it liberates from the water in which it is dissolved. It is probable that its germicidal effect is similar. In other words, chlorine and ozone come to the same thing in the end, namely, nascent oxygen. Chlorine, however, has the advantage of

more ready solubility and of cheapness. It is used technically in three forms, all of which, however, act in the form of free chlorine, and not as compounds.

(*a*) *Chlorine Gas.* — Until within recent years chlorine has been manufactured commercially by the Weldon or some similar process. In the Weldon process hydrochloric acid is made to react with a complex mixture of manganese hydroxide and lime — "Weldon mud" — the reaction being essentially

$$MnO_2 + 4HCl = MnCl_2 + 2H_2O + Cl_2,$$

although in reality it is much more complex.

Recently, however, electrolytic processes have been developed by which the cost of manufacture has been materially reduced, particularly where cheap water power is available. The difficulties in the way of using gaseous chlorine are chiefly the cost of transportation, difficulty and danger in handling the gas, and the difficulty of accurately measuring the amount of gas added to the effluent. On the other hand, if the magnitude of the work would warrant the installation of an electric chlorine generating plant, there is reason to believe that there would be a great economy in the preparation and direct use of the gas, and the disadvantages noted would be obviated to a large extent. This matter of cost will be more fully discussed in another place.

(*b*) *Oxychloride Process. Hermite Process.* — The electrolysis of ordinary salt yields chlorine and caustic soda. It is claimed that if magnesium salts be present, as in sea water, a secondary reaction occurs by which there are produced certain oxides of chlorine. Three oxides of chlorine are known: Cl_2O and Cl_2O_3, the anhydrides of hypochlorous and chlorous acids, respectively, and chlorine peroxide, ClO_2. The latter is formed only under exceptional conditions and is extremely unstable. The others unite instantly with water to form the corresponding acids. There seems to be no legitimate reason for assuming the presence of any compounds in this electrolyzed sea water except compounds analogous to those which we know are produced in the case of the sodium and the calcium salts; namely, hypochlorites. The hypochlorite of magnesium seems to be an unstable compound, readily hydrolyzing to magnesium hydrate and hypochlorous acid. This fact is sufficient to account for the higher disinfectant value observed in the use of electrolyzed sea water as compared with equivalent amounts of available chlorine in the form of bleaching powder.

Rideal made an extensive series of experiments at Guildford,

England, where he was able to test the effect of the "oxychloride" treatment upon raw and septic sewages and upon effluents of primary, secondary, and tertiary contact beds. The following tabulated summary of his results will show about what may be accomplished. By the term "available chlorine" (av. cl.) is meant the chlorine value as obtained by titration with arsenious acid. The results, especially as regards the removal of *B. coli*, are all that can be desired. Examinations of the few organisms remaining in the sewages and effluents after treatment showed them to be largely organisms of the hay bacillus group, aërobic spore-forming bacteria, which are probably beneficial in the further oxidation of the organic matter. Absolute sterilization required very high concentration of chlorine.

TABLE I—SUMMARY OF RIDEAL'S EXPERIMENTS AT GUILDFORD, ENGLAND, ON THE USE OF OXYCHLORIDE IN STERILIZING RAW SEWAGE, SEPTIC EFFLUENTS, AND THE EFFLUENTS OF PRIMARY, SECONDARY, AND TERTIARY CONTACT FILTERS

Sample of	Av. cl. Parts per million.	Time of contact.	Organisms per Cubic Centimeter.					
			Total.		B. coli.		B. enteritidis.	
			Initial.	Final.	Initial.	Final less than	Initial.	Final less than
Sewage	30	4.3 hours	23,000,000	50,000	1,000,000	1.0	1,000	10.0
	50	4.3 hours	23,000,000	20	1,000,000	0.2	1,000	0.2
	70	4.3 hours	23,000,000	10	1,000,000	0.2	1,000	0.2
Septic effluent	25 to 44	1.0 hour to 4.0 hours	2,500,000 to 4,500,000	20 to 600	100,000 to 1,000,000	1.0 to 0.2	10 to 1,000	1.0 to 0.2
First contact	20	40 minutes	. .	. .	100,000	0.2	. .	. .
	20	2 hours	. .	. .	. .	. .	20 to 100	0.2
Second contact	10.6	. .	1,000,000 to 2,000,000	40	1,000,000	0.2	10 to 1,000	0.2
Third contact	2.5	1.0 hour	. .	. .	1,000 to 10,000	0.2	. .	. .
	2.5	4.5 hours	. .	. .	. .	. .	10 to 100	1.0
	0.5	0.5 hour	. .	. .	1,000 to 10,000	0.2	. .	. .
	0.5	4.5 hours	. .	. .	. .	. .	10 to 100	0.2

(*c*) *Chloride of Lime.*—Chloride of lime, so called, is a mixture of calcium hypochlorite, calcium chloride, and impurities. Its efficiency as a disinfectant is due to the action of the hypochlorite, which decomposes slowly, giving off oxygen and free chlorine. Thresh has used chloride of lime at Illford, England, for the sterilization of the effluent of a chemical precipitation plant. The addition of 140 to 200 parts of

the chloride was found to give a nearly sterile effluent after the latter had flowed in a closed conduit for a mile. Commercial chloride in this country will average 35 per cent. available chlorine. Upon this basis the amount of chlorine used was 50 to 100 parts. The chloride would, therefore, seem to be as efficient as the so-called oxychloride, and in fact is probably a similar compound.

During the past year experiments have been carried on at this station to determine the efficiency of bleaching powder in the sterilization of the effluent of a trickling filter. A preliminary series of tests was first made, covering a wide range of concentrations of bleaching powder. These tests were made in bottles. A strong suspension of bleaching powder was made up and analyzed for available chlorine by the arsenious acid method. Portions of this solution were then measured into bottles, each containing 1 liter of the effluent from the trickling filter. The available chlorine was again determined in a sample withdrawn from the bottle. Determinations of the total organisms present in the effluent before adding the disinfectant and at stated intervals thereafter were made. Plates were made with standard nutrient gelatin, incubated at 20° and counted on the third day.

The results of these tests are summarized in Table II, and in Table III are calculated into percentage figures:

TABLE II — PRELIMINARY TESTS OF EFFICIENCY OF BLEACHING POWDER IN THE STERILIZATION OF A TRICKLING FILTER EFFLUENT

TEMPERATURE 20°

Experiment No.	Bottle No.	Av. cl. Parts per million.	Bacteria per Cubic Centimeter. Initial.	Thirty minutes.	One hour.	Two hours.	Five hours.	Twenty hours.
1906								
I. Started February 13	Blank	0.0	80,000	. .	. .	. .	. .	640,000
	1	3.5	70,000	850	. .	500	50	50
	2	10.6	80,000	500	. .	900	200	50
	3	55.0	90,000	50	. .	180	. .	50
	4	108.0	60,000	. .	. .	. .	. .	50
II. Started February 20	Blank	0.0	133,000	. .	. .	. .	. .	. .
	1	25.0	122,000	190	90	. .	. .	. .
	2	25.0	99,000	100	180	. .	. .	. .
	3	37.0	128,000	50	80	. .	. .	. .
	4	100.0	124,000	27	36	. .	. .	. .
III. Started March 7	Blank	0.0	176,000	. .	. .	272,000	. .	. .
	1	2.0	153,000	. .	300	100	. .	. .
	2	5.0	130,000	. .	100	50	. .	. .
	3	5.0	146,000	. .	100	300	. .	. .
IV. Started March 13	Blank	0.0	80,000	. .	. .	86,000	. .	. .
	1	0.25	96,000	. .	33,000	38,000	. .	. .
	2	0.50	84,000	. .	9,100	4,600	. .	. .
V. Started March 20	Blank	0.0	230,000	. .	. .	200,000	. .	. .
	1	1.0	212,000	. .	39,000	1,900	. .	. .
	2	1.5	146,000	. .	500	100	. .	. .
VI. Started April 17	Blank	0.0	24,000	. .	. .	68,000	. .	. .
	1	5.0	25,000	. .	. .	500	. .	. .
	2	10.0	35,000	. .	. .	100	. .	. .

TABLE III — SUMMARY OF PRELIMINARY EXPERIMENTS

Experiment No.	Available chlorine. Parts per million.	Organisms Killed. Per Cent. of Initial Numbers. Thirty minutes.	One hour.	Two hours.	Five hours.	Twenty hours.
I	3.5	98.7	. .	97.8	99.6	99.9
	10.6	98.9	. .	98.9	99.7	99.8
	55.0	99.9	. .	99.9	99.9	99.9
II	25.0	. .	99.8	99.9	. .	. .
	37.0	. .	99.94	. .	. .	. .
	100.0	. .	99.97	. .	. .	. .
III	2.0	. .	99.8	99.9	. .	. .
	5.0	. .	99.85	99.9	. .	. .
IV	0.25	. .	65.6	70.9	. .	. .
	0.50	. .	89.2	94.2	. .	. .
V	1.0	. .	81.5	99.1	. .	. .
	1.5	. .	99.6	99.9	. .	. .
VI	5.0	. .	98.2	98.2	. .	. .
	10.0	. .	. .	99.6	. .	. .

These results indicate clearly the practical impossibility of obtaining a sterile effluent in this way. Neither the addition of large amounts of bleaching powder, up to 100 parts of available chlorine per million, nor the storage of the effluent for periods of time up to twenty hours proved entirely effectual. It is further shown that a concentration of about five parts per million of available chlorine and a storage period of about two hours give practically the maximum efficiency possible with the process.

Upon this basis, therefore, a practical test of the process was made. A large trickling filter at the Sewage Experiment Station, filtering raw sewage at the rate of five thousand gallons per day, was used. A solution of bleaching powder was made up in a fifty-gallon barrel of such strength that when added to the effluent at the rate of two gallons per hour it would supply the effluent with about five parts per million of available chlorine. It was not possible on such a small scale to regulate the flow accurately, and there was some variation in the amount of available chlorine found in the effluent. This value was determined each day when the samples were taken for bacterial examination. It averaged about five parts per million, and the variation was no more than may be expected in the case of a larger plant with less careful supervision.

The mixed effluent and sterilizing solution passed into a settling basin built on the principle of a Dortmund tank, and designed to give a mean storage of approximately two hours. Regular examinations of the effluent before admixture with the sterilizing solution and after this two-hour period of contact were made. The total bacteria growing upon gelatin at 20° were determined by the usual plating method.

The removal of total organisms was found to be 99.96 per cent. The determination of *B. coli* was made by the bile broth presumptive test recommended by Jackson (1906). Positive results were obtained in 33 per cent. of the tests made upon the untreated effluent at a dilution of $\frac{1}{1000000}$, indicating that the organism was present on the average to the extent of about 330,000 per cubic centimeter. After treatment positive tests were obtained in 22 per cent. of 1 c.c. samples, indicating that on the average there was one organism present in 5 c.c. of effluent. Upon this basis the average removal of fermenting organisms (presumably *B. coli*) was 99.993 per cent.

The detailed results of this series are shown in Table IV.

TABLE IV—EXAMINATIONS OF EFFLUENT FROM TRICKLING FILTER BEFORE AND AFTER STERILIZATION WITH CHLORIDE OF LIME, AVAILABLE CHLORINE, FIVE PARTS PER MILLION

Date.	Organisms per Cubic Centimeter.		Gas Production in Bile Broth.	
	Before treatment.	After treatment.	Before treatment. Dilution, $\frac{1}{100000}$ c.c.	After treatment. Dilution, 1 c.c.
August, 1906.				
11	270,000	69	+ 0	+ 0
13	630,000	41	0 0	+ 0
14	135,000	406	+ +	+ 0
15	230,000	21	0 0	0 0
16	250,000	37	+ 0	0 0
18	110,000	40	0 0	+ 0
20	90,000	54	+ 0	0 0
21	220,000	22	0 0	0 0
23	. .	. .	+ 0	0 0
Average	240,000	86	33 per cent.	22 per cent.
Average removal		99.96 per cent.		99.993 per cent.

A series of laboratory experiments was carried on at the same time to determine the germicidal power of the bleaching powder solution upon *B. typhosus*. Strong bouillon cultures of this organism were made in sterile tap water. After the number of organisms initially present was determined, suitable amounts of the bleaching powder solution were added, and determinations were made of the organisms remaining alive at stated intervals. The results of these tests are shown in Table V.[1]

[1] The writers desire to express their acknowledgments to Dr. R. P. Cowles, of Johns Hopkins University, for valuable assistance in carrying out the bacteriological work involved in these experiments.

TABLE V—Experimental Results Showing the Germicidal Action of Bleaching Powder Solutions upon B. Typhosus.

Experiment No.	Available chlorine. Parts per million.	Organisms per Cubic Centimeter.							
		Initial.	One minute.	Twenty minutes.	Forty minutes.	Sixty minutes.	Two hours.	Four hours.	Twenty-four hours.
I	4.2	1,300,000	1,000,000	300,000	59,000	9,800	800	. .	15
II	5.4	5,500,000	4,450,000	1,350,000	850,000	675,000	450,000	450,000	6,000
III	4.7	1,200,000	. .	465,000	190,000	133,000	50,000	. .	54
IV	6.9	3,200,000	20,000	200	. .	300	20	. .	10
V	3.5	5,800,000	20,000	800	200	500	11	0	1
VI	3.5	3,200,000	70,000	200	100	200	26	16	8

Except in Experiment II, the reduction in twenty-four hours is practically complete, and in two hours is satisfactory for all purposes for which such treatment would be undertaken, the enormous initial numbers being taken into consideration. The phenomenon of a few specially resistant organisms is a very common one in all investigations of germicides, whether of heat, cold, desiccation, or chemical disinfection, and is particularly marked here. The results of Experiment II are in disagreement with the others. Whether they represent a specially resistant culture of the organisms or whether the results are due to some error in the experiment cannot be stated.

Summarizing, it may be said, as a result of these experiments, that a concentration of five parts per million of available chlorine from bleaching powder, acting for a period of two hours, will remove 99.96 per cent. of the total bacteria and practically eliminate the intestinal organism, *B. coli*, and any typhoid organism present.

Cost of Chlorine in Various Forms

With the electrolytic process in use at Niagara Falls, where cheap power is available, the manufacture of chlorine and of bleaching powder is carried out very cheaply. Commercial bleaching powder can be purchased in the Eastern market at about 1 cent per pound, guaranteed 40 per cent. available chlorine. In other parts of the country the additional freight charges might make the cost somewhat higher. On the convenient basis of 1 cent the actual cost of the chlorine is 2.5 cents, and the cost of adding one part per million of

available chlorine to the effluent would be 21 cents per million gallons, or $1.05 per million gallons for five parts. Bleaching powder is made by the action of chlorine upon caustic lime, so that chlorine in this form will obviously cost more than as the free gas. To develop at once its full bleaching or disinfecting action it is necessary to use it in acid solution, as is done in commercial bleaching processes. An investigation of the reactions involved leads us to believe that the total available chlorine, as indicated by the analysis, is eventually set free in a solution of organic matter, such as sewage, especially in the presence of sunlight; but it is probable that the reaction proceeds more and more slowly as it reaches the end, and that in the time available for treatment it is not safe to count upon more than 75 per cent. of the available chlorine being actually used. Rideal observed that there was an immediate loss of available chlorine corresponding roughly to the strength of the sewage or effluent under treatment, and that afterward the loss of available chlorine was very gradual, his explanation being that there were two distinct kinds of organic matter present. With the knowledge that free carbonic acid, always present in sewage, is able to react with the hypochlorite liberating chlorine, we are inclined to the view that the preliminary action noticed was due to this cause. Free gaseous chlorine, on the other hand, is all "available" and ready for immediate use. As the time element is one of immense importance in the design and cost of a sterilization plant, this item alone deserves much weight. Moreover, the use of chlorine gas possesses certain other advantages over the bleaching powder. It adds nothing else to the sewage, whereas bleaching powder adds a certain amount of insoluble material and considerable hardness. It seemed advisable, therefore, to obtain, if possible, some actual cost data on the production of electrolytic chlorine. Through the courtesy of Messrs. A. G. Paine, Jr., president, and J. R. Crocker, superintendent, of the New York and Pennsylvania Company, the following statistics have been obtained, based upon actual costs in a large paper mill using the McDonald electrolytic cell.

Each cell will produce 22 pounds of chlorine and 22 pounds of caustic soda per day of twenty-four hours, with the use of 2.08 kilowatts of current. One kilowatt hour is therefore equal to 0.46 pound of chlorine. The cost of power, made under the most favorable conditions by a modern compound condensing engine, burning "run-of-

the-mine" coal at $2 per ton, is estimated at not over $52 per kilowatt year, or 0.6 cent per kilowatt hour. The cost of chlorine is therefore about 1.3 cents per pound, a trifle over half the cost of the chlorine in bleaching powder. If, as we have intimated, this form of chlorine shall be found to be 25 per cent. more efficient than the other, and if the original cost of installation be not too great, it seems that for large works, at least, the manufacture of chlorine might well be undertaken. Even at 2 cents per pound the cost of treating a million gallons of effluent with one part per million of chlorine would be reduced to 16.6 cents, or 83 cents per million gallons for five parts. Moreover, this expense would be considerably offset by the value of the caustic soda produced at the same time.

6. Copper and Its Compounds. — Rideal has experimented recently with copper salts, and finds them efficient in the sterilization of effluents. While its expense would seem to prohibit the general use of copper, it is undoubtedly a suitable disinfectant for water cress and oyster beds.

Johnson and Copeland (1905) obtained the following reduction of total organisms in effluents:

	Copper sulphate. Rate per million.	Per Cent. Reduction.	
		Three hours.	Twenty-four hours.
First series, average of three sets	5	90.0	99.9
	10	98.0	99.95
	20	98.5	99.96
Second series, average of three sets	10	40.0	99.7
	20	60.0	99.9
	40	88.0	99.95

They find action most rapid during the first hour. They estimate the cost for chemicals alone at $5 per million gallons of effluent, treated with ten parts per million, or $10 for twenty parts, which they consider prohibitive. More experimental data on the use of copper salts are needed before we can judge of their value. Their effect will also depend largely upon the character of the water.

7. Miscellaneous. (*a*) *Permanganate*. — Potassium and sodium permanganate have been used at times for the oxidation of organic matter in streams. At London sodium permanganate is added to the Thames regularly when it becomes too foul at times of low water. The application here is to destroy odors and putrescible material, but it

undoubtedly partially sterilizes the water. Its use has been proposed for rendering effluents of chemical precipitation plants non-putrescible. The cost is greater than chlorine compounds, which would seem to be fully as efficient.

(*b*) "*Amines*" *Process.* — This process was developed by H. Wollheim in England. It is claimed that trimethylamine treated with lime or other alkali produces a very poisonous substance. Herring brine is used for the amine. A large excess of lime is used, and the mixture used to precipitate crude sewage. Klein made a test of the process at West Horn in 1889, and found that a clear, non-putrescent, and sterile effluent could be obtained. Similar results were obtained at Wimbledon, where the bacteria on the sewage were reduced from 768,000 to none. The sludge is also non-putrescible. The process has never been developed further. (Great Britain, 1902, A, Quest. 5206.)

Conclusions

Summarizing the more important points of the present discussion, we may state:

Ordinarily it is not the function of the sewage filter to remove bacteria from the sewage. In the case of the modern rapid filters, we are not at all certain as to the fate of the dangerous germs of disease.

Where extensive shellfish interests are at stake it will sooner or later become necessary to protect the neighboring waters from pollution, and in this case the total absence of pathogenic bacteria must be assured.

This result may be attained by the ultimate use of sand filters or by chemical sterilization.

Among the possible agents for use in sterilization, chlorine, either as chloride of lime or as free gaseous chlorine, appears to have the highest cost efficiency. An amount of the former which will yield five parts per million of available chlorine was found to have destroyed 99.96 per cent. of the total bacteria and practically all of the *B. coli* present in the effluent of a trickling filter treating crude Boston sewage, the time of contact having been two hours. The estimated cost of such treatment is $1.05 per million gallons of sewage.

The use of gaseous chlorine, manufactured at the disposal works by electrolytic methods, would in the case of larger works consider-

ably reduce this cost. An approximate estimate places the cost of such treatment at about 85 cents per million gallons of sewage, allowing five parts of chlorine per million. It is probable that the chlorine in this form is somewhat more efficient.

The process as thus outlined is entirely feasible, and in the case of large works it is cheaper than sand filtration. Further experiments upon a large scale are now under way to test the results of these experiments and to get more accurate cost and efficiency data.

Among other agents which may be used, copper sulphate seems to be the most promising, and further experimental data are needed to show what efficiency may be expected from its use.

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CONTRIBUTIONS FROM THE LABORATORY OF SANITARY CHEMISTRY

XI

ANALYSES OF AMERICAN MALT VINEGAR

BY A. G. WOODMAN AND G. P. SHINGLER, JR.

THE composition of cider vinegar as made in this country has been carefully studied, and several valuable contributions to our knowledge of it have been made, notably by Smith[1] and by Leach and Lythgoe.[2]

Published analyses of malt vinegar, on the other hand, are comparatively rare, being limited practically to the few analyses made by Hehner[3] in 1891, and extensively quoted in the literature, and to the analyses given by Allen in his "Commercial Organic Analysis."[4] Moreover, these refer to English samples, the only analyses of American specimens being three published by Smith in the paper previously mentioned.

On this account, and because malt vinegar is an article of food for which the demand in this country is increasing, it seemed desirable to undertake the analysis of several authentic samples of American origin.

The samples, seven in number, were secured directly from the manufacturers, who were aware of the purpose for which the vinegar was to be analyzed, and who signified their willingness, if desired, to furnish a sworn guarantee of the purity of the product. Sample G was made by the spontaneous fermentation of sour ale, and while the results are published as a matter of general interest they are not included in the final averages.

METHODS

Specific Gravity. — This was determined with a pyknometer at 15.5°.

Total Acid. — 5 c.c. were diluted to 200 c.c., nearly neutralized

[1] J. Am. Chem. Soc., 1898, **20**, 3.

[2] J. Am. Chem. Soc., 1904, **26**, 375.

[3] Analyst, **16**, 82.

[4] Edition 3, Vol. I, p. 470.

with $\frac{N}{10}$ sodium hydroxide, heated to boiling to expel carbon dioxide, and the titration finished in the hot solution, using phenol-phthalein as indicator.

Solids. — 5 c.c. were measured into a tared, flat-bottomed platinum dish, heated for two hours in contact with the steam of a boiling water bath, and weighed.

Ash. — 25 c.c. were evaporated to dryness and carefully incinerated in a muffle. The contents of the dish were then treated with boiling water, filtered through an ashless filter, and the residue washed with hot water. The filter and residue were dried and ignited in the dish, giving the weight of insoluble ash.

Alkalinity of Ash. — This was determined on the water-soluble ash, and on the insoluble portion by boiling with an excess of $\frac{N}{10}$ hydrochloric acid and titrating the excess of acid with $\frac{N}{10}$ sodium hydroxide and phenol-phthalein.

Soluble Phosphoric Acid. — The solution of the ash from 25 c.c. of the sample was evaporated to dryness, the residue taken up in boiling water, and the phosphoric acid determined by titration with uranium acetate.

Insoluble Phosphoric Acid. — The insoluble ash was moistened with dilute nitric acid, evaporated, carefully incinerated, and taken up in boiling distilled water. The titration with uranium acetate was carried out as before, the uranium solution being standardized in this case against pure tricalcium phosphate.

Polarization. — 50 c.c. of vinegar, clarified with 5 c.c. of basic lead acetate, was filtered and the filtrate polarized in a 220 mm. tube. The polarization is expressed in degrees Ventzke for 200 mm.

Reducing Sugar after Inversion. — 25 c.c. were diluted to 50 c.c., and 5 c.c. of concentrated hydrochloric acid were added. The solution was heated to 70° C. in three to five minutes, maintained at that temperature for five minutes, cooled, nearly neutralized with potassium hydroxide, and made up to 100 c.c. Reducing sugar was determined in an aliquot part by the Defren-O'Sullivan method.[1]

Total Proteids. — The determination was made by the Kjeldahl method, the factor 6.25 being used in calculation.

[1] TECH. QUART., 1897, 10, 167.

Results

Table I is a compilation of the previous analyses; the results of the present investigation are given in Table II. All results, unless otherwise stated, are given in percentages.

TABLE I

	Specific gravity.	Acetic acid.	Total solids.	Ash.	C.c. $\frac{N}{10}$ acid for alkalinity of soluble ash.	C.c. $\frac{N}{10}$ acid for ash of 100 grams vinegar.	P_2O_5, mgs. per 100 grams.	Albuminoids.	Analyst.
1	. .	3.07	3.26	.39	. .	13.58	130.0	. .	Hehner
2	. .	2.88	2.72	.41	. .	15.85	120.0	. .	Hehner
3	. .	3.70	4.01	.31	. .	6.98	130.0	. .	Hehner
4	. .	6.48	2.44	.31	. .	14.34	88.0	. .	Hehner
5	. .	5.73	2.46	.47	. .	16.79	92.0	. .	Hehner
6	. .	4.16	1.68	.22	. .	3.21	96.0	. .	Hehner
7	. .	3.79	4.23	.32	. .	14.34	67.0	. .	Hehner
8	1.0205	6.61	2.81	.55	. .	21.26	66.0	.76	Allen
9	1.0170	6.39	2.67	.34	. .	19.04	77.0	.62	Allen
10	1.0228	5.26	3.96	.40	. .	24.55	93.0	.60	Allen
11	1.0160	4.86	2.31	.47	. .	. .	57.0	.62	Allen
12	. .	5.90	2.21	.28	6.0	. .	12.5	. .	A. W. Smith
13	. .	5.16	2.67	.26	6.0	. .	9.0	. .	A. W. Smith
14	. .	4.40	2.04	.23	5.6	. .	9.2	. .	A. W. Smith
15	. .	4.01	1.75	.20	4.4	. .	9.5	. .	A. W. Smith

Remarks. — In this table the figures for the alkalinity have been recalculated in several instances in order to afford a uniform basis for comparison. All the samples are of English origin except 13, 14, and 15, which are American. The first seven are supposed to be made from malt only, 8, 9, 10, and 11 from mixtures of malted and unmalted grain, the starch entirely hydrolyzed by diastase.

TABLE II

Sample.	Specific gravity, 15.5° C.	Total acid as acetic.	Total solids.	Ash.	Ash soluble in water.	Insoluble ash.	Alkalinity of soluble ash, c.c. $\frac{N}{10}$ acid for 100 grams vinegar.	Alkalinity of insoluble ash, c.c. $\frac{N}{10}$ acid for 100 grams vinegar.	Soluble P_2O_5, mgs. per 100 grams vinegar.
A	1.0271	5.70	4.88	.43	.29	.14	15.18	15.94	13.32
B	1.0143	5.50	2.02	.27	.14	.13	5.35	13.03	16.66
C	1.0131	4.53	1.60	.25	.15	.10	9.88	14.30	36.36
D	1.0121	5.21	1.55	.16	.11	.05	4.35	8.03	10.40
E	1.0188	6.81	2.51	.21	.13	.08	3.50	19.09	32.02
F	1.0128	4.60	1.37	.19	.15	.04	12.05	9.32	47.78
G	1.0235	6.04	3.32	.17	.05	.12	3.40	20.39	27.74
Maximum . .	1.0271	6.81	4.88	.43	.29	.14	15.18	20.39	47.78
Minimum . .	1.0121	4.53	1.37	.16	.11	.04	3.40	8.03	10.40
Average . .	1.0159	5.48	2.46	.24	.14	.09	7.67	14.58	23.47

TABLE II — *Continued*

Sample.	Insoluble P_2O_5, mgs. per 100 grams vinegar.	Polarization.	Reducing sugars (maltose) before inversion.	Reducing sugars (dextrose) after inversion.	Proteids (N × 6.25).	Per cent. ash in total solids.	Per cent. reducing sugar in total solids.	Per cent. P_2O_5 in total solids.	Ratio soluble to insoluble P_2O_5.
A	22.86	6.05	2.30	1.84	.59	8.81	47.13	0.74	1 : 1.716
B	8.78	0.31	1.05	0.83	.53	13.37	51.98	1.26	1 : 0.527
C	43.03	1.75	0.90	0.61	.29	15.63	56.24	4.60	1 : 1.185
D	8.97	2.56	0.60	0.40	.14	10.32	38.72	1.25	1 : 0.863
E	17.42	2.76	1.07	0.77	.22	8.38	42.63	1.97	1 : 0.534
F	19.47	0.06	1.01	0.63	.19	13.87	73.72	4.91	1 : 0.407
G	25.99	3.18	2.84	2.09	.62	5.11	85.55	1.32	1 : 0.937
Maximum . .	43.03	6.05	2.84	2.09	.62	15.63	85.55	4.91	1 : 0.407
Minimum . .	8.78	0.06	0.60	0.40	.14	5.11	38.72	0.74	1 : 1.716
Average . .	20.93	2.38	1.39	1.02	.37	10.78	56.56	2.29	1 : 0.890

CONTRIBUTION FROM THE DEPARTMENT OF GEOLOGY

REPORT ON THE GEOLOGICAL EXCURSION THROUGH NEW MEXICO, ARIZONA, AND UTAH, SUMMER OF 1906

BY DOUGLAS WILSON JOHNSON

IN connection with the study of certain problems in physiographic geology, and for the purpose of supplying certain deficiencies in our teaching collection in that subject, I some time ago formulated the plans for a wagon trip through some of the more inaccessible parts of the Southwest. It seemed to me that such a trip would make possible the collection of data which might solve, or at least make desirable contributions to, some of the problems in connection with the history of the plateau province of Arizona and Utah, the origin of the volcanic buttes in the Mount Taylor district, New Mexico, and the character and origin of the Basin Ranges of Utah; also the collection of valuable illustrative material for the courses in topographic, lithologic, and paleontologic geology. The execution of the plans for such an excursion was made possible last spring by an award of $250 from the Austin Fund, a grant of similar amount from the Sturgis-Hooper Fund of Harvard University, and by private gifts from friends of the Institute amounting to $500.

Dr. H. W. Shimer, of the Institute Geological Department, and Mr. C. H. Decker, a graduate of the Columbia University School of Mines, looked after the stratigraphic and economic geological problems more particularly, Dr. Shimer securing much material which will add greatly to the value of the Institute's teaching collections, and which will form the basis of future publications. The main energies of the party, however, were directed to the study of problems and the collection of material which were related to physiographic geology.

The party left Albuquerque, central New Mexico, on the 31st day of May, with camp outfit and provisions for a ten days' trip in the

Mount Taylor district. This region was made classic by the report of Major C. E. Dutton on the volcanic necks and other volcanic features there represented. These necks were described as showing vertical columnar structure in many cases, being of enormous size and nearly cylindrical in shape or somewhat elongated in one direction, while the adjacent sedimentary beds were not much disturbed. In recent years some doubt had been expressed as to the interpretation of these features, it being argued that vertical columnar structure should not be expected as a prominent feature in volcanic necks, but was rather indicative of some other origin for the famous buttes; that it was difficult to understand how a cylindrical neck or plug could be forced up through sedimentary beds, especially if those beds were not profoundly disturbed. Professor Jaggar has concluded that the Mato Tepee, or Devil's Tower, of Wyoming (fully described in his report on the geology of the Black Hills), a butte which bears a striking resemblance to some of the New Mexico types, must be the remnant of an old laccolith, basing his conclusion on the vertical columnar structure, the undisturbed sediments at the base of the tower, and the association of the butte with undoubted laccoliths still well preserved.

It was in the hope of securing data bearing on this problem that we examined a number of the finest examples of the buttes in the Mount Taylor district. The study led to the following conclusions: (1) The buttes are undoubted volcanic necks of large size, one of them rising over 2,000 feet above the surrounding valley lowland. (2) Many of them show good columnar structure more or less nearly vertical; it is believed that this position is due to the floor of the crater's acting as the cooling surface for the upper portion of the neck, at least, rather than the probably heated walls of the conduit up through which the lava came; the columns developing at right angles to the cooling surface would thus be vertical, instead of radial or irregular, as formerly supposed. (3) The necks are more or less cylindrical in shape, and have come up from unknown depths without in the least disturbing the surrounding sediments in most cases, thus showing that enormous plugs may force a clean passage through sedimentary rocks, however difficult the process may be of explanation (4) The age of the rocks, the general geology and physiography of the region, and the detailed character of the necks were studied. Typical rock specimens, fossils, and photographic views were obtained. The results of this study will be published during the year under the title, "The Volcanic Necks of the Mount Taylor Region, New Mexico."

After returning to Albuquerque, our party went by rail to the Big Bug mining district, some twenty-five miles southeast of Prescott, Arizona, where we made our headquarters in the northern end of the Bradshaw Mountains while outfitting for the trip across the deserts to the north. We experienced considerable difficulty in securing suitable horses and wagons, but after some delay procured an outfit of five horses, two wagons, the necessary saddles, tent, bedding, provisions, etc., and on the 19th of June started northward. We soon turned eastward to the valley of the Verde River, making a study of the large limestone series of that district with a view to determining its age and origin. Thence turning northeast we followed up Oak Creek to the foot of the great Mogollon escarpment, which terminates the plateau district on the south, and after a few miles of the steepest and roughest road encountered during the whole summer reached the summit, where we could look far to the northward and see the San Francisco Mountain rising high above the surrounding forest-covered plateau surface, while below us to the south lay the arid lands of the basin region. Here we were able to trace the relations of several great faults which help to determine the rectangular pattern of the southern margin of the plateau in this region. Continuing northward to Flagstaff, we found extensive lava flows covering portions of the plateau which do not appear on the previous maps of the region. From Flagstaff we turned southeast to Walnut Canyon, the region of some of the best cliff-dwellings in the Southwest. Dr. Shimer made a detailed study of the geological section exposed in the canyon walls, collecting a series of characteristic fossils and determining the character of the beds which weather into overhanging ledges and thus afford the conditions utilized by the cliff-dwellers in making their homes.

We next passed around the western base of the San Francisco Mountain, and established a camp well up the northwest slope. From this camp we made a two days' trip with pack outfit to the summit of the old volcano to study the effect of ancient glaciation at the highest levels. Although so far south, the peak rises to such an altitude (12,794 feet above sea level) that its summit was occupied by a local glacier during the glacial period, this glacier eroding a splendid cirque in the very centre of the volcano, and leaving a prominent terminal moraine a short distance down the valley into which the cirque opens. Even today the snows lie on the higher levels and in sheltered places

until well into the summer, our camp on the night of July 6 being pitched between two snowdrifts over 10 feet high. Five days later we were in the bottom of the Grand Canyon, 10,000 feet lower, our party almost prostrated by the intense heat.

From the San Francisco volcano we went to a point near Grand View on the rim of the Grand Canyon of the Colorado, where we established a camp for several days. After visiting several points on the rim of the canyon, we descended the old abandoned Red Canyon trail, spending two nights and parts of three days in the Grand Canyon, returning to the summit of the plateau by the Grand View trail. We then returned to the northern side of the San Francisco group, where we investigated a recent cinder cone and lava flow, so recent, in fact, that erosion has as yet produced no effect on either cone or flow, both being perfectly formed, dense black in color, and fairly free from soil or vegetation. Studies were made also of numerous other cones and flows throughout the plateau region, resulting in the establishment of the fact that the so-called "period of basalt outflow" is really divisible into at least five or six different periods, with long erosion intervals between them. Collections of fossils and rock specimens from the Grand Canyon and other parts of this district were made.

Crossing eastward to the Little Colorado River, and then northward to the trading post at Tuba, we secured our last supply of grain and provisions before entering on the most strenuous part of our journey, the crossing of the Painted Desert. Already we had suffered some difficulty in securing water fit to drink and sufficient grass for the horses. At Tuba we were disappointed to find no grain, except a little Indian corn, which the horses did not seem to regard with favor. With little prospect of grass on the desert, the outlook was discouraging. The weather was now intensely hot, so that we found it advisable to travel mainly at night, resting during the day. Accordingly we usually arose about three or four in the morning, drove until the heat became oppressive, rested until six in the evening, then drove until well into the night, or until we lost our way in the darkness. During the middle of the day we erected a canvas awning to protect ourselves from the sun, but even in the shade thus afforded our thermometer registered 115° and we found it difficult to sleep.

We secured good water at Willow Springs, a short distance from Tuba, and began the journey northward along the western base of the Echo Cliffs. These cliffs are produced by erosion on an eastward

dipping monocline of sandstone, but have a much sharper form and steeper back slope than would appear normal for the gentle monoclinal dip. This sharpness of form had been noted by Professor Davis, of Harvard University, on an excursion some years before, and tentatively ascribed to possible faulting along the back slope of the monocline. Several traverses across the monocline at critical points showed the absence of any such faults, but revealed the fact that cross bedding at high angles and with rather uniform eastward dip caused the rocks to weather with steep eastward slopes, thus determining the peculiar topographic feature observed in the cliffs. Numerous landslides on a large scale were observed, thus confirming the previous observations of Professor Davis regarding the recent revival of erosion in the Grand Canyon region, with consequent undermining of previously graded slopes, causing extensive landslides in the areas near the revived streams.

By the time we reached the crossing of the Colorado River at Lee's Ferry, near the Utah line, our horses were pretty well exhausted, owing to the hot weather, lack of grain, sandy roads, and scarcity of grass, good grass being found at only two points along the road from Tuba. At Lee's Ferry we had counted on obtaining grain, but were greatly chagrined to find that the supply on hand at that point had been nearly consumed, so that the best we could do was to secure twenty-five pounds of oats, this to last five horses for over one hundred miles of desert and mountain roads!

Ten miles beyond the ferry we found ourselves facing a serious problem. The horses first stumbled repeatedly, then stopped short and refused to go another step. There was no grass, and it required a hunt of several hours to find a little pool of salty water and get the horses to it, after having first taken them out of the harness and let them rest. That evening we succeeded in getting them a little farther, but found no grass or water. The next morning we managed to reach good water and a little grass. Here it became necessary to leave one horse and one of the wagons behind and pull the other wagon by means of four horses. Walking ourselves, we were thus able to make about twelve miles, over very sandy roads and under an intensely hot sun. Returning with the horses the second day, the other horse and wagon were brought up, this method being persisted in until the foot of the Kaibab plateau on the western side of the desert was reached, an average advance of about six miles a day being made. After a short rest at a spring at the foot of the Kaibab, the horses were able to

pull the wagons, one at a time, up to the higher country on the summit, where we found better grass. The Kaibab plateau and the Kanab desert were crossed with less difficulty, although the long delay had so far exhausted our own store of provisions that the members of the party had to get along with scanty rations the last four days before reaching a new base of supplies.

In spite of the difficulties encountered this part of the trip was most profitable. We were able to make a study of the streams which are dissecting the east Kaibab monocline, and to discover marked differences between the lower and upper courses of the streams, indicating two distinct erosion periods in the development of the region. This conclusion was confirmed by the study of certain terraces discovered farther south along the monocline and by a consideration of the relation of one of the larger valleys to the monocline, all of which features offer strong evidence in favor of the recently proposed theory that the faults and folds of the plateau province are much older than the present Colorado River, as opposed to the former belief that the river's course was first established and that the faults and folds are of later development.

From Kanab, in southern Utah, our party went north to Upper Kanab to study the terraces which terminate the high plateaus on the south. The Tertiary beds, forming the highest part of this series, have been considered of lacustrine origin until late years, when the possibility of a subaërial origin has been entertained by some observers. We secured evidence, both here and farther north, strongly indicating a subaërial origin. The origin of the Triassic and Jurassic beds are also in doubt, and we made some studies as to detailed structures which we hope will aid in solving this problem. Collections of the rather scarce Jurassic fossils were made, and some points of interest regarding lava flows in the valleys noted.

Returning to Kanab, we then went southward across the Uinkaret desert to the lower portion of the Toroweap valley near the Grand Canyon. This region was of special interest, as offering undoubted evidence as to the age of two of the great faults of the plateau province. The region being difficult of access on account of the scarcity of water, evidence believed to be available had not yet been secured, and to supply this lack we attempted the trip. Dutton reported that all of the faults of this region were topographically recent, that wherever the faults were present cliffs of the upthrow side overlooked the lower

downthrow side, and that the Sevier and Toroweap faults in this special district were separate and distinct. Professor Davis has recently advanced the theory that the faults are much more ancient, so ancient, in fact, that erosion has once obliterated the topographic effects of faulting by leveling off the country; while recent erosion, removing the soft beds, has caused the reappearance of fault line cliffs wherever the old faulting brought hard and soft beds opposite each other, the cliffs thus facing toward the upthrow in some cases, toward the downthrow in others. Thus it was shown that the cliffs of today are often located on the side where the lowland was originally found, while the lowland of today has been worn out of the rocks which were faulted up, reversing the original topographic effects of faulting. Professor Davis further believed that the Sevier and Toroweap faults were continuous, being one and the same.

A somewhat detailed study of the region in question enables us to add a considerable amount of evidence which strongly corroborates the theory of a very great age for the faults, and which makes the theory of recent faulting wholly inadmissible. A traverse of some of the more inaccessible parts of the region, however, showed that the two faults were quite distinct, overlapping each other for many miles, but the Toroweap being from six to fifteen miles or more west of the southern extremity of the Sevier. The age of a part of the rock series of this region is in doubt because of the scarcity of fossil remains. We were fortunate in securing some fossils from the doubtful strata, which we hope will serve to establish their age more definitely.

After returning from the Toroweap country we went westward to the Hurricane fault, and spent several days in camp on the bank of the Virgin River, waiting until one of the greatest floods in the river's history should subside sufficiently to enable us to ford. This enforced delay gave time for a careful study of the features of the fault scarp for several miles south of the river. This region has been described in some detail by Messrs. Huntington and Goldthwait in an admirable paper. They established the occurrence of two distinct periods of faulting along the great fracture with an intervening erosion period. A careful study of the relation of certain lava flows to the fault enabled us to discover a third period of movement or faulting quite as distinct as the two previously noted, with long time intervals separating it from those other periods. The relation of a number of successive lava flows and their effect on the former topography were worked out.

Northward from the Virgin our course lay along the foot of the western rim of the high plateaus on the eastern border of the Great Basin region. We traced the Hurricane fault for a hundred miles or more to the northward, studying the details of the faulting in many different localities. Recent faulting was discovered along the western side of Round Valley; the stratigraphic series of that region was found to be quite unlike the representations on earlier maps, and the region was remapped as far as practicable. Some fossils were collected from the more recent members of the series. Collections of rhyolite, trachyte, and andesite from type localities were made for the purpose of supplementing the Institute study series. The character of the Tertiary beds in several regions was studied with regard to the question of their origin, and numerous observations of miscellaneous geological features were noted.

As we neared the Salt Lake City region we had opportunity to observe the topographic features of the ancient shore lines of the former Lake Bonneville, type examples of dissected fault block mountains, and other features which have made this classic ground for all students of geology. The numerous photographs and sketches that were made of these typical features will add much to the effectiveness of the courses in topographic geology.

In the villages and towns just south of Salt Lake City the outfit was disposed of and the party disbanded. Dr. Shimer went to the Yellowstone National Park for a short trip, Mr. Decker to the Bingham mining district, while I returned east by way of Butte, Montana.

It will be seen that the results of the expedition include the collection of data bearing on a number of special problems of some scientific importance, as well as a variety of miscellaneous observations which should be permanently recorded. It is proposed to publish discussions of the larger problems as separate reports during the coming year in different geological journals, and the miscellaneous observations, together with a brief abstract of the larger problems, as one report.

Our party was in the field nearly four months, traveling over fifteen hundred miles by wagon and probably at least three hundred more on horseback.

THE TEACHING OF BIOLOGY AND SANITARY SCIENCE IN THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

By C.-E. A. WINSLOW

The early history of the Biological Department at Technology is a history of men who builded better than they knew, and whose work has been justified to an extent far beyond their vision by new and unexpected developments of applied science. Courses in zoölogy, botany, paleontology, physiology, and comparative anatomy were included in the first annual catalogue of the Institute, issued in 1865; but these subjects had at that time little direct connection with a "school of industrial science." It is probable that President Rogers believed, as the faculty of the Institute have ever since held, that not only chemistry and physics (with its varied developments in mechanics and hydraulics and electricity), but geology and biology as well, should form integral parts of a liberal scientific curriculum. Their view is one which the lapse of time has only served to justify; but beyond this general aspect thirty years of progress have extended the domain of biology into new fields of direct technical application.

The earliest graduates of the Institute in natural history became teachers and investigators; and this is one of the avenues of usefulness to which work in biology at the Institute has ever since led some of its students. Both men and women graduates of the course have found congenial openings in education, and the department is represented on the faculties of many colleges and universities. Another important contingent of students has received special instruction, coming from the secondary and normal schools about Boston to take particular courses adapted to their needs. The number of teachers working as regular or special students in the biological laboratories of the Institute is somewhat less today than it was ten years ago, but the opportunity still lies open for a peculiarly helpful mutual relation between the Institute and the public school system.

The training of teachers is, however, one of the less important phases

of the work of the Biological Department. When General Walker became President of the Institute he opened for it a new line of usefulness. Professor W. T. Sedgwick was called from Johns Hopkins in 1883 to take charge of the biological side of natural history, the Course VII of that day. Soon after, the name of his department was changed to biology, and its work was reorganized, with the aim of making it a preparation for the subsequent study of medicine. President Walker said of this new adaptation of the department: "The cultivation of the perceptive powers, the systematic practice of the art of observation, the use of instruments of precision, the early familiarity with the structure, habits, and workings of living objects, which are involved in the course, must be conceded to afford the kind of training best suited to enable the scholar to pursue the subsequent study of medicine with the greatest advantage, and cannot fail to prove of peculiar value to the physician in his professional practice."

There can be no doubt that a mastery of biology offers a good preparation for the study of medicine. Modern theories of health and disease require a sound biological conception of the organism and its relation to the environment. Modern advances in clinical diagnosis and therapeutics demand an increasing knowledge of bacteriology and physiological chemistry. Johns Hopkins recognized these facts several years ago by requiring the completion of special work in biology before entrance to the medical school; and requirements of this sort are likely to become more general.

The main development of biological work at the Institute has, however, followed another line; one which could not possibly have been foreseen at the time it was first organized, but one for which it found itself most fortunately prepared when the emergency arose — the science of bacteriology and micro-biology.

The connection between microbes and fermentation had been demonstrated by Pasteur before 1870, and his studies of the silkworm diseases which ravaged the great industry of the south of France pointed to bacteria as the cause of these maladies. Between 1875 and 1878, Robert Koch definitely proved that splenic fever was caused by a specific bacterium. It was only in the eighties, however, after Koch had devised the solid culture method of isolating and cultivating bacteria, that the science of bacteriology began to make rapid progress. The germ of tuberculosis was discovered in 1882, and the determination of the organisms which cause cholera, diphtheria, tetanus, and typhoid fever followed very quickly.

Just at this time the attention of the authorities of the state of Massachusetts was being turned toward the sanitary condition of the water supplies and rivers of the commonwealth. In 1887 Professor T. M. Drown, then head of the Chemical Department of the Institute, was asked to conduct, under the auspices of the State Board of Health, an exhaustive investigation of the water supply problems of the state. Professor William Ripley Nichols had also taken a keen interest in the new developments of sanitary science; and on his death in Europe, after a summer (1886) spent in the study of laboratory methods in the older universities, some tubes of the new Koch gelatin medium were found among his effects and sent over to the Institute. The interest with which this was received and the hesitation as to just how it was to be used (since the gelatin had become liquefied *en route*) are still remembered in the Biological Department. It was not long, however, before the new methods were mastered. In 1888 the first course in bacteriology was offered by Professor Sedgwick, and in the same year the now classic biological studies of the Lawrence Experiment Station were placed under his direction.

President Walker grasped at once the potential importance of these new lines of investigation. In 1888 he said in his annual report, speaking of sanitary bacteriology: "The great advances recently made in this line of investigation, and the almost limitless possibilities of the future in this respect, have not only caused the minds of many of our students to turn in that direction, but have created a demand from the outside for skilled bacteriologists, which up to this time the Institute has not been able fully to meet." Two years later he again pointed out the growing promise of this field of applied science in relation to "the activity of soils, the fixation of nitrogen, the preservation of foods, the preservation of timber, the purity of public supplies (such as air, water, milk, and ice), as well as the more urgent and difficult problems of drainage, sewerage, and the public health."

It was a clear vision that could grasp the close relation of bacteriology to such varied fields of applied science in the year 1890. After fifteen years many of these potential applications are still made only in tentative and experimental fashion. The study of the nitrogen-fixing organisms, which Mr. Edward Atkinson called the greatest discovery of the nineteenth century, has scarcely yet begun to bear fruit. Our telephone and telegraph companies still renew their poles once in eight years instead of employing an expert to study the organisms which rot

them away at the surface of the ground. In many directions, however, much progress has been made. Denmark took the lead in applying biology to industry in its great breweries; and the first course of instruction in this country on the microörganisms of fermentation, offered at the Institute in 1894, was founded on a study of the methods in use at Copenhagen. Today it is universally recognized that the secret of success in the brewing industries lies in the cultivation of desirable forms and the elimination of "disease" yeasts and bacteria. In the dairy the same thing is true. The harmful fermentations of milk, butter, and cheese, as well as the normal ripening of the last two products, all depend on certain microörganisms. Those which are desirable may be isolated and inoculated in pure cultures, as has recently been done with success at Wesleyan University in the case of certain cheeses. Those which are harmful may be forestalled by controlling the conditions of manufacture according to principles determined from experimental investigations. In canning and food preserving, important aid has been furnished by researches carried on at the Massachusetts Institute of Technology and elsewhere. In the tanning industry and in the preparation of fibres by various macerating processes, practical men are turning to experts for assistance. In tobacco curing and in the manufacture of various acids and dyestuffs promising fields are opening up, as yet almost unworked.

Bacteriology in its relation to the public health has developed even more rapidly than in its application to the arts and industries. A whole field of novel sciences has grown up, bound together by the fact that all bear on a single biological problem — the adaptation of the human mechanism to its environment, and in particular in relation to certain microparasites. Taken together they form what is practically a new profession, founded on its own special basis of pure knowledge — the profession of sanitary science. The care of the public health has ceased to be merely a subsidiary function of the practice of medicine. Like physiology and anatomy and bacteriology, and many other independent sciences, it owes its inception largely to the spirit of scientific research and the spirit of public service which the medical profession has always manifested in so splendid a degree. Medicine is the mother of sanitary science. It is, however, a token of wisdom in mothers to recognize the moment when their children have attained their majority; and the time has now clearly come when sanitary biologists and sanitary engineers may stand on their own feet. Professor Sedgwick, in an address

before the American Public Health Association, indicated the striking readjustment which has almost imperceptibly taken place in the relation between medical practitioners and the public health. He points out first that curative and preventive medicine, or hygiene, are today widely separated, and second that even the sphere of hygiene is naturally separable into two distinct hemispheres, one dealing directly and chiefly with individuals or masses of individuals, the other directly and chiefly with their environment.

"It is today absurd for the average well-trained medical student to think of becoming an expert in such branches of hygiene as water supply, sewerage, heating and ventilation, street building, street cleaning and watering, garbage collection and disposal, gas and other forms of light supply, ice supply, milk supply, the abatement of nuisances, etc. These belong rather to the sanitary engineer, sanitary chemist, and sanitary biologist; to sanitation rather than hygiene.

"Closer to the physician's own work, and yet almost a science in themselves, are the problems of personal hygiene — muscular exercise, sleep, foods and feeding, bathing, clothing, mental work, and the like. Halfway between personal and public hygiene lie such subjects as school hygiene and school sanitation, epidemiology, quarantine, the control of foods and drugs."

Administrative positions in connection with sanitary science and the public health demand a knowledge of the whole field, but the man of executive ability will generally reach the top by way of a sound training in one of three narrower paths which lead to it. These three primary careers are those of the physician, the laboratory expert, and the engineer.

That part of public hygiene which falls generally to the town or city board of health is concerned chiefly with the control of the contagious diseases, and includes diagnosis by inspection and laboratory examination, isolation, disinfection, and serum therapy. The staff of a city health office includes, besides the subordinate inspectors, experts of two types. For clinical recognition of such diseases as smallpox and leprosy, for medical inspection of schools, and for the administration of vaccine and antitoxin, men trained as expert diagnosticians are required; and these must be primarily physicians.

On the other hand, the methods of parasitology which are used for the laboratory diagnosis of disease demand no special medical training, but a general foundation of chemistry and histology and bacteriology, which may be gained much better at a scientific school than in an

institution devoted to the teaching of medical practice. The preparation of serums and vaccines demands specialization along lines of pure bacteriology, and not of medicine. The testing of disinfectants and the various special problems which come to the laboratory of a health board are not medical problems. All these fields of expert work, along with the bacteriology of milk and the chemistry and bacteriology of sewage and water, belong to the trained laboratory specialist, who represents the newer applications of pure science to the work of public hygiene. The formation of the Laboratory Section of the American Public Health Association, devoted to "the theory and practice of bacteriology, chemistry, etc., as applied to the advancement of sanitary science," and the admirable work which that section has accomplished offer a good index of the growth of this profession.

There remains, thirdly, the engineer, the man who deals directly with the inanimate environment and remodels it in accordance with the advice of the physician and the laboratory expert. Sanitary engineering has risen to a supreme importance, with the aggregation of masses of people in great cities, which makes the problem of healthful conditions at once more difficult and more imperative. The city is an organism which demands as the first essential for its life a supply of pure water, food, and air, and the removal of its waste products. The purification of water supplies, by the English process of slow filtration through sand or by rapid mechanical filters of the American type, is a pressing need for a large majority of the cities in the United States. It requires preliminary expert surveys, expert construction, expert operation and maintenance. A good air supply is as vital a necessity as a good water supply. We breathe eighteen times a minute and do not drink as many times a day; tuberculosis carries off ten times as many victims as typhoid fever. The erection of sanitary tenements, the ventilation of factories, and the elimination of the dust and dampness and poisonous fumes which cause an excess of phthisis in the "dangerous trades" demand scientific research and skilled construction. The removal of wastes is no less important than the supply of air and food. The pollution of streams and estuaries, with the consequent danger to water supplies and to shellfish industries, is a problem of the first magnitude. Columbus, Ohio, has set the example, which many other cities must follow, of an expert preliminary investigation of the local problem of sewage disposal; for the modern methods of sewage treatment are technical processes which require delicate adjustment. In the treat-

ment of industrial wastes, which now destroy many streams instead of being so utilized as to prove a source of profit, there is much to be done. Scientific garbage disposal in the United States demands expert investigations, which have so far been almost wholly lacking.

For the carrying out of this great sanitary campaign able and well-trained recruits are needed. It is the chief aim of the Departments of Biology and Sanitary Engineering of the Institute to furnish these recruits. The Biological Department aims to develop the first, the laboratory expert, who in some cases of special aptitude will later become a health officer or administrator. A good foundation of general chemistry and bacteriology leads to a training in the chemistry and bacteriology of air, water, and food, chemical and microscopical examination of foods and drugs, the principles of sanitary science and municipal sanitation, vital statistics, and the study of parasitology as applied to the laboratory diagnosis of the infectious diseases. Instruction in the bacteriology of sewage and water has so far been carried forward, parallel with the best current progress in that science. The staff of the department must, however, be enlarged in the near future if it is to maintain a similar leadership in some of the newer outgrowths of the science. In the training of laboratory experts in biology there should be sound general instruction in the complex problems of immunity and serum therapy; and there should be the most thorough technical training in the methods and results of the new science of the parasitic *Protozoa*, which is probably as full of possibilities today as was the science of bacteriology twenty years ago. In both these branches the Institute needs instruction by specialists who are advancing their own lines of study by productive research.

For the engineering work of the campaign against disease the Department of Sanitary Engineering has been organized, founded on the triple base of engineering, chemistry, and biology. Its students are first soundly trained along civil engineering lines, in surveying, railroad and highway engineering, stereotomy, applied mechanics, structures, and hydraulics. With these, the rudiments of chemistry and biology are also taught, since the sanitary engineer must be to some extent a chemist in order that he may plan and interpret sanitary analyses, even if he does not carry them out himself; and he must be to some extent a biologist, acquainted with the significance of bacteriology and the laws which govern the causation of disease.

For graduate students unusual facilities for advanced study are

offered by the Sanitary Research Laboratory and Sewage Experiment Station founded in connection with the Biological Department by an anonymous friend of the Institute. This Station furnishes an opportunity for investigating the problems of sewage purification such as probably no educational institution in the world can parallel. The treatment of the sewage of Boston is here being studied as it would be studied on a practical scale; and septic tanks, sand beds, contact beds, and trickling filters are available for special investigations. The Experiment Station has already attracted graduate students from various parts of the country, and has reacted upon the general instruction of the department in a most helpful way. Interesting results upon the treatment of industrial wastes have been obtained by members of the Station staff, working in coöperation with the United States Geological Survey, and important extensions of its work are contemplated in the future.

With regard to the third sanitary expert, the physician in public health work, the Institute has also something to offer. The courses in biology and engineering at Technology are specialized directly along sanitary lines, but not one of our medical schools has yet made a definite attempt to educate medical men to serve as experts in sanitation. The ordinary physician is no better fitted for his side of public health work than the ordinary civil engineer or the ordinary systematic biologist would be for theirs. There is great need of medical experts trained in sanitary science; and to meet this need the Biological Department of the Institute is prepared to offer a two years' course to graduates of ordinary medical schools, which will adequately fit them for positions as health officials for city or state.

In all these directions there is need for men of the right sort, energetic, patient, open-minded, and well trained. From the professions, already well developed, of sanitary bacteriology and sanitary chemistry and sanitary engineering calls are constantly coming which cannot be met for lack of men. Some conception of the need may be gained by recalling the demands which have already been made upon Technology men for work along these lines. With the Massachusetts State Board of Health there are at this writing twelve Institute men — five engineers, including the first and second assistant engineers; five chemists, including the chief chemist, the first assistant chemist, and the chief analyst of food and drugs; and two biologists, including the biologist of the Lawrence Experiment Station. In Ohio the engineer-

ing department of the State Board of Health is entirely recruited from Technology graduates, including the chief engineer and four assistants. The State Boards of Health of New York and Minnesota have appointed Institute graduates as their chief engineers within the past three months. The chief engineer of the State Water Supply Commission of Pennsylvania and his first assistant are Technology men. To New Jersey we have sent the assistant chemist of the State Sewage Commission, to Maryland the chemist and bacteriologist of the Baltimore Sewage Commission, and to Louisiana the chemist and bacteriologist of the New Orleans Water and Sewerage Board. Vermont has one of our men as chemist, Rhode Island one as assistant chemist, and to Connecticut and Iowa we have sent assistant bacteriologists. The national government, through the United States Geological Survey, is making extensive studies of water supply and stream pollution problems, which fall into direct line with these state and municipal investigations; they are being carried out by one of our graduates as chief hydrographer, while half a dozen others are employed as his assistants.

In the municipal field, we have furnished Richmond, Virginia, Plainfield, New Jersey, Montclair, New Jersey, and Elizabeth, New Jersey, with health officers. The city bacteriologist of the city of Boston and the director of the Water Supply Laboratory of the city of New York, with several of his assistants, are Institute men. The epidemiological studies at Waterville, Maine, Washington, District of Columbia, and Cleveland, Ohio, the investigations on the Chicago Drainage Canal, the experiments on water purification at Louisville, Kentucky, Cincinnati, Ohio, New Orleans, Louisiana, and Pittsburg, Pennsylvania, have been carried out under the direction of Technology graduates. The construction of the filter plants at Albany, New York, Harrisburg, Pennsylvania, Watertown, New York, Little Falls, New Jersey, New Milford, New Jersey, Springfield, Massachusetts, and many others was in the hands of Institute engineers; and Institute engineers and bacteriologists are at present in charge of the operation of the plants at Watertown, New York, New Milford, New Jersey, Little Falls, New Jersey, Springfield, Massachusetts, Birmingham, Alabama, Washington, District of Columbia, Columbia, South Carolina, Charleston, South Carolina, Knoxville, Tennessee, and Superior, Wisconsin. The construction of the new disposal work at Columbus, Ohio, is being carried out with a Technology engineer in charge, and four Institute men among the engineering assistants.

All this is only a beginning, for the work which remains to be done in the United States is still enormous. In the five years, 1898–1903, there were 126 cities with populations over 30,000. Eighty-two of them had average typhoid death rates of more than twenty-five per 100,000 population. Such death rates are due in almost every case to the use of polluted water, and in every case to some gross sanitary neglect. As epidemics occur or as the public conscience is awakened these water supplies must be purified. In 1902 Mr. G. W. Fuller estimated that among the cities and towns with a population over 3,000 there were 1,100 sewerage systems and only ninety disposal plants. It is very probable that the next two decades will see a large proportion of the thousand systems, which now discharge untreated sewage, equipped with modern disposal plants. The systems of state supervision of water supply and sewage disposal now in force in Massachusetts and Ohio and New Jersey and Pennsylvania are certain to be extended to the other progressive states of the Union.

This is the field for the Institute's graduates in sanitary science. The Biological Department continues to offer a fundamental scientific training to those entering upon the study and practice of medicine It prepares men and women for the teaching of natural science in the school, the high school, and the college. It furnishes specialists in the increasing applications of biology to the development of the arts and industries. Its chief function, however, is to train recruits for the new crusade against disease; and this function is limited only by the number of volunteers and by the facilities necessary for their equipment.

BOOK REVIEWS

Street Railway Investments[1]

Each year adds something to the completeness of this work as a guide to investors in street railway securities. The alphabetical arrangement by states and towns within each state makes it easy to compare adjacent properties, and the placing of each interurban road under the largest city on its line renders the full index at the back of the book almost unnecessary. The work includes all the street railways of the United States, the insular possessions, Cuba, and Canada. The essential facts in regard to each railway are given, and in the case of the older and larger roads fairly complete financial and operating statistics covering a period of years are compiled. The work also includes forty-nine maps, showing the systems of fifty-two separate companies, mostly interurban.

The book probably meets the needs of those for whom it is prepared, but one cannot help regretting the lack of general tables of statistics, such as are given in Poor's Manual and in the reports of the Interstate Commerce Commission. It is perfectly evident from a glance at the several volumes of this work that there has been a rapid growth in street railway mileage and in the consolidation of systems during recent years, but one would like to see this growth more definitely measured. This growth is shown in a way, however, by some general tables of gross receipts. For example, in 1902 there were thirty-eight companies whose gross receipts exceeded $1,000,000 each, with a total of $159,336,273. In 1905 there were fifty-one such companies, with a total gross income of $227,946,916. The growth in number of companies having gross incomes of from $100,000 to $1,000,000 was still more marked. There were 107 such companies in 1902 and 209 in 1905, and the gross earnings of this class had increased from $32,201,783 to $64,706,527 during the three years. Without doubt a considerable

[1] American Street Railway Investments. Supplement to the Street Railway Journal. New York: McGraw Publishing Co., 1906. 13, 38 + 432 pp., fol.

part of this increase was due to the consolidation of previously existing small roads; but the fact that the number of small roads has increased at the same time, though not so rapidly, indicates a remarkable growth in new enterprises. Another striking aspect of this growth in railway systems is noted when one looks over the list of states. Wyoming among all of the states and territories is the only one which has no street railways. All this is, of course, simply another indication of the wonderful progress and prosperity of the country.

If one were to criticise this work, it would be along the line of statistics of physical plant, and this would be really a criticism of the roads themselves because of the incompleteness of their reports at this point. In many cases financial and operating statistics are given for a number of years, while there is nothing to indicate additions to equipment or increase in mileage during the same period. The reports would be much more useful to the investor if these figures were included. It is evident, however, that promoters and directors of street railways as well as other corporations are coming to realize the necessity of making more adequate reports, and it is probable that future volumes of this work will afford still more complete and satisfactory data than the one under review. C. W. D.

The Steam Turbine

In a new work entitled, "Steam Turbine Engineering,"[1] this modern form of engine is treated from the standpoint of one interested in the commercial side of power generation. Short chapters are given to descriptions of the mechanical features of well-known turbines, but the major portion of the book is devoted to comparative studies of economy, size, cost, and conditions of operation of turbines and auxiliary machinery now in use in many parts of the world.

During the rapid development of the turbine since 1900, the principles involved in new constructions, together with approximate details of improved designs, have generally been published soon after the patents were granted; but authentic data as to cost, and reliable figures showing the steam and heat economy, have, for obvious reasons,

[1] Steam Turbine Engineering. By T. Stevens and H. M. Hobart. New York: Macmillan, 1906. 814 pp., 516 il.

usually been withheld. Such information, nevertheless, has gradually accumulated and is now available in the recent technical magazines and transactions of engineering societies. Messrs. Stevens and Hobart have accomplished the difficult task of collecting, systematizing, and comparing most of this data, adding thereto a good deal of valuable information secured directly from turbine manufacturers.

Although written for English-speaking engineers, the tabular portion of this book is nearly all in the metric system, with pressures expressed in kilograms per square centimeter and temperatures in Centigrade. English units also are given in many cases. For tests where the turbine output was measured by means of a dynamo the observed results are quoted; where it was measured by other means a dynamo was assumed, having a *standard efficiency* determined after investigating very many generators of types suited to turbine requirements. Thus the output for all tests is reduced to kilowatts, and the economy is, therefore, easily compared.

Chapters XV and XVI are particularly interesting, dealing with performances of reciprocating engines built since 1899 and comparing them with average results for turbines, showing the effect of variation in load, pressure, vacuum, and superheat.

Conditions of operation, with data concerning the buildings, boilers, turbines, condensers, and pumps for a large number of reciprocating and turbine plants, are given in Chapters XVII to XXI. Chapter XXII presents, in tabular form, a digest of more or less important data from twelve large electric generating stations, where steam turbines furnish all the motive power. Eighty different items are listed, including not only the turbines and auxiliaries, with special features of the generators and electrical equipment peculiar to turbine stations, but also a mass of data concerning the boiler plants and coal-handling apparatus. Each station is fully illustrated with photographs showing arrangement of buildings and machinery. Chapters XVII to XXII alone would make a very acceptable book on steam turbine practice.

More than a hundred pages are devoted to the marine steam turbine, but here the matter and illustrations are nearly all taken from previous publications, with little that is really new and considerable that is obsolete. The data tables in this chapter are left blank in many places where the desired information could easily have been obtained.

Examination of the voluminous bibliography of turbine literature

since 1896, given in the last chapter, will convince one of the value of this book in collecting under one set of covers a summary of the information previously scattered through so many different journals, many of which are not accessible to the average reader.

J. C. Riley.

Food Materials and Their Adulterations[1]

On account of the present general interest in all things pertaining to the propaganda of "pure food" the appearance of a revised edition of this book is particularly timely. As the author very truly says in the preface to this edition, "Conditions have changed with marvelous rapidity in the twenty years since this little book was written, and in no quarter more than in the food problem."

This is well shown by the changes made necessary in the treatment of some of the subjects discussed. The question of coffee substitutes, for example, is not mentioned in the earlier edition, these benefactors of mankind having been introduced since that time. Analyses made at some of the State Experiment Stations are quoted which show up clearly the ridiculous claims to "high nutritive value" put forward in behalf of some of these preparations. In the discussion of cereals and cereal foods the modern breakfast foods are much more in evidence than formerly. In the early edition the question of the wholesomeness of "tinned foods" was devoted for the most part to the danger from solution of the tin and consequent harm; the question is now largely one of artificial coloring, addition of chemical preservatives, and the imposition upon the consumer by the substitution of cheaper and less wholesome ingredients.

Two points made by the author are worthy of special commendation: the suggestion in regard to the establishment of a "high school museum" for exhibiting conditions as regards local goods, and the stress laid upon the need for cleanliness in handling, preparing, and exhibiting food, lack of which is a source of danger far greater than adulteration with cheap but wholesome substitutes.

Some of the tests for the purity of sugar given in the earlier edition

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[1] Food Materials and Their Adulterations. By Ellen H. Richards. Third edition, revised and rewritten. Boston: Whitcomb & Barrows, 1906.

are omitted, which is just as well. The case against sirups is made to appear rather blacker than is warranted, the high percentage of adulteration being largely because the manufacturers have had free rein in the past, satisfactory methods for the detection of adulteration of maple sirup being very recent. It is not always made sufficiently clear that the analyses referred to and the ratio of adulteration found are those of twenty-five years ago.

The adulteration of spices is not now so much a matter of the addition of foreign material, to be detected by the microscope, as of the blending with cheaper grades, shown only by careful chemical examination.

It might be mentioned in passing that the simple test described on page 153 for the detection of alum in baking powders is not a general one, and a negative result is not evidence that alum is absent.

The general appearance of the book is a considerable improvement over that of the earlier one, but the list of references shows lack of care on the part of either compiler or proof-reader.

A. G. WOODMAN.

A TEXT-BOOK OF SANITARY CHEMISTRY[1]

A RÉSUMÉ of the chapter headings will indicate the wide scope of this book of 325 pages: The Atmosphere; Fuels; Heating and Ventilation; Lighting; Water; Purification of Water Supplies; Disposal of Household Wastes and Garbage; Use of Soap and Bluing; Disinfectants, Antiseptics, and Deodorants; Food; Cellulose, Starch, Dextrine, Legumes; Bread; Breakfast Foods and Other Special Foods; Sugars; Glucose; Leaves, Stalks, Roots, etc., Used as Food; Composition and Food Value of Fruits; Edible Oils and Fats — Food Value of Nuts; Meat; Eggs; Milk, Cheese, and Butter; Non-Alcoholic Beverages; Alcoholic Beverages; Food Accessories; Preservation of Foods — Coloring of Food Products; Economy in the Preparation and Selection of Food — Dietaries.

Under each heading a very considerable mass of information is given, which makes the book a desirable one for the general reader

[1] A Text-Book of Sanitary and Applied Chemistry, or The Chemistry of Water, Air, and Food. By E. H. S. Bailey. New York: Macmillan, 1906.

as well as for the student. For class work numerous well-chosen illustrative experiments are given.

Both this and Mrs. Richards's book, reviewed above, should be on the shelves of every high school and college library.

The author states well in the closing paragraph of the Introduction the basic purpose for which the book was written: "A thorough understanding of the facts of applied chemistry will not make the skilled workman, nor will the theories of chemistry make the accomplished cook; but a broad and thorough knowledge of the underlying principles will go very far toward developing common sense in hygiene and in the selection and preparation of food." A. G. WOODMAN.

PRODUCER GAS[1]

THIS little book gives a list of 287 questions on the fundamental definitions involved in producer-gas manufacture, upon its history and status, its uses and cleaning, and upon the construction and handling of gas producers.

The material is well chosen and the explanations clear and concise, so that any one after its perusal should have a good understanding of the subject.

The only feature open to unfavorable criticism is the relatively high cost of the book, it being about double the usual price of scientific books, and this in view "of the limited literature on the subject that has been available in the past" (answer to question No. 190).

A. H. GILL.

A FIVE-FIGURE TABLE OF LOGARITHMS[2]

THIS is a small book, convenient to carry in the pocket, and contains nineteen pages of text, beginning with a section in which the theory

[1] Catechism on Producer Gas. By Samuel S. Wyer. New York: McGraw Publishing Co. 42 pp. $1.00 net.

[2] Five-Figure Logarithms of Numbers and Angular Functions for the Use of the Engineer, Constructor, and Student. By H. H. Suplee. Philadelphia: Lippincott, 1906. 91 pp., 16mo. $2.00.

of logarithms is explained very simply and clearly. Then follows a description of the tables of logarithms, with directions for obtaining the logarithm from a number and the number from the logarithm, with interpolation by the usual method. A separate section is devoted to the logarithms of fractions, with directions for decimal points, and the like. These sections are followed by others giving numerical examples of the use of logarithms for various purposes. The table of logarithms of numbers gives the logarithms to five places for the numbers from 1 to 1,199. It is clearly printed and well spaced, and has marginal tables of proportional parts. This is followed by the table of the logarithmic angular functions from 0° to 180°. The book ends with the table of hyperbolic logarithms to seven places for the numbers from 1.01 to 134.

This book undoubtedly will prove useful for ordinary calculations. The clearness of the type and the small size and lightness of the volume make it very convenient. It is a pity, however, that the binder did not put the book together in such a way that it will lie open easily. And the book would have been better if the table of logarithms of numbers had been arranged so that the change in the first place of the number should always come at the top of the left-hand page. This would require the addition of only an inch and a quarter to the length of the book, and would have the further advantage of permitting leads to be used in the tables of angular functions and hyperbolic logarithms, thus giving a better spacing between the lines.

In the arrangement of the vertical columns of the table of logarithms of numbers the Germans generally employ a greater number of ruled lines to guide the eye from the numbers at the top of the column to the logarithms below. For example, in "Erdmann und Kötner, Naturkonstanten" (Berlin, Springer, 1905), we find a ruled line between the column headed 0 and 1, between 3 and 4, and between 6 and 7. This divides the table into one column for the whole number on the left and into three blocks of three columns each for the significant figures of the fourth place. This has been found in practice by the reviewer to be an improvement over the traditional English and American fashion, followed in this volume, of dividing the table by a single ruled line between the columns headed by 4 and 5.

American and German Education Compared[1]

This little book is a critical comparison of the conditions in American and German universities and schools for higher education, and is written especially with the aim of presenting to German readers that which is of merit in American institutions. The author's experience was gained by one year's residence in America, during which time he occupied the station of research associate at the Massachusetts Institute of Technology. By nature and training a keen observer and student of conditions, he has gained a remarkably thorough appreciation of the methods and the ideals of American higher education as typified in the Massachusetts Institute of Technology and Harvard University. As he himself emphasizes, he has not immediately embodied his ideas in print, but has first allowed them to mature during several months after his return to his work in his native country. He thus can give a fairer survey of the subject, and not one distorted by the accidental being mistaken for the typical, as has been done by some who have essayed to express themselves upon this subject.

America is, according to Dr. Böttger, the land of experimentation in educational matters. It is only during the last thirty years that the American universities have developed to their present importance. Their life is, therefore, younger and thus more energetic.

The length of time occupied in the preparatory schools by the youth of both countries is about equal — an average of twelve years; yet the graduate of the American preparatory school has only the training requisite for entrance to the highest class of the German "gymnasium." The reason for this is, naturally, that the American boy is not so severely pressed in his studies, whereby more opportunity is given for his very essential physical development.

The first years of the American college are still in the nature of preparation for his special line of study; thus the transition from a condition of dependence in the preparatory school to one of independence in the higher school is a gradual one. Much stress is laid by the author upon the American system of supervision of the student's work, as compared with the German system of complete freedom. The advantages of the American method are evident: that many students are guarded against mistakes which would entail serious consequences.

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[1] Amerikanisches Hochschulwesen, Eindrücke und Betrachtungen. By Dr. W. Böttger, Privatdozent at the University of Leipsic Leipsic: Wilhelm Engelmann, 1906. 70 pp.

Contrasted to this, the German system suddenly throws the student wholly upon his own responsibility; upon entrance into the university his choice of studies is unrestricted, and he takes no examination until his final one, when he deems himself prepared to try for the degree of "doctor" from the university. The German contends that his system possesses the advantage that those who do not make the proper use of the freedom accorded to them will sooner or later fall out, so that only those will reach the goal who properly understand the privileges and duties of the student's freedom. This argument, however, presupposes that the student already has that which he must first acquire. In America the same goal is striven for, but with fewer losses, in that the transition to the condition of independence is made gradual.

The difference in the ideals of education in the two countries may be summed up in the following: In America the aim of the higher education is to increase the efficiency of the average man, while in Germany the stress is laid upon bringing the best to the highest development. The author seems to reach the conclusion that due precaution is exercised in America to prevent the invasion of the less diligent into the ranks of the learned professions, while, at the same time, pains are taken to develop the less gifted, who are on this account the more in need of education.

The author discusses at some length the matters of state and private schools, the organization of instruction, the cost of instruction and scholarships, athletics, and the love and loyalty of the alumni of a school for their Alma Mater. As evidence of the last mentioned point, he cites the active part taken by the alumni of the Massachusetts Institute of Technology in the discussion of the plan for the merger of that school with Harvard University. Indeed, he ventures the opinion that the final miscarriage of that plan was to be attributed, at least in part, to the vigorous opposition on the part of the alumni.

Many matters of interest are treated which cannot be touched upon in this review. The author has dealt very lightly with our failings and has devoted himself chiefly to pointing out to his countrymen, with whom education is an established science, that which has been attained in a country where education is still in the state of development. It is a matter of interest to learn those points in our system which are deemed commendable, or worthy of study, by a student trained in the Old World educational ideals. This work is of additional interest as treating the subject especially from the viewpoint of education in the

exact natural sciences, previous writers, in the main, having treated the subject in its relation to general culture.

ARTHUR A. BLANCHARD.

THE POLARIZING MICROSCOPE[1]

THIS book of only 147 pages is a noteworthy and commendable example of how concise and yet clear a treatise on a complicated and abstruse branch of applied optics can be made when the writer is master of his subject. While Professor Weinschenk ostensibly writes for the petrographist, there is much which is in touch with the work of microscopists generally, and with that of chemists who have learned the value of micro-chemical analysis.

Dr. Weinschenk himself states in his preface that he seeks to meet the need of the "non-specialist"; to give a book which, while brief, will make the fundamental principles of micro-crystallography intelligible to beginners, and be a guide to the practical use of the polarizing microscope rather than a reference work for experts. Certainly the author seems to have succeeded remarkably well.

The six chapters cover the following subjects: Fundamental optical principles of the microscope and polariscope, very briefly given; description of apparatus. Testing and adjusting of the polarizing microscope. Observations made with ordinary light, such as simple methods for determining index of refraction; and the bearing of refraction on the interpretation of images in the microscope; determination of cleavage, size, thickness; color classification and use of reflected light. Use of parallel polarized rays to show double refraction, and its bearing on the number and position of crystal axes, as shown by pleochromatic effects with a single nicol. Determination of planes of polarization by use of two nicols; the stauroscope; interference effects and their use in measuring double refraction; use of "compensators." Observations with converging polarized rays and discussion of methods of making such observations; optical effects given by crystals of different systems in converging light; circular polarization; determination of the angular position of crystal axes; twin and other anomalous crystals.

[1] Anleitung zum Gebrauche des Polarisationsmikroskops. By Dr. Ernst Weinschenk. Second edition. Freiburg im Br.: Herder, 1906.

In an appendix there are descriptions of various accessory apparatus, among which are heating appliances for observations at high temperature, projection apparatus, and a convenient and very simple type of photo-micrographic camera. Finally, there is a tabulation and summary of the methods given, a set of simple rules for distinguishing the different crystal systems by their optical behavior, and a very full index.

The illustrations, which are numerous and excellent, greatly aid the text. The typography is of that high class characteristic of the best German bookmaking. G. W. ROLFE.

UNIV. OF MICH.
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TECHNOLOGY QUARTERLY

AND PROCEEDINGS OF THE

SOCIETY OF ARTS

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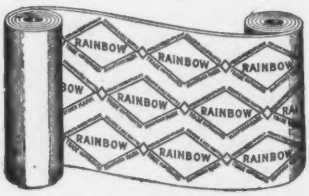

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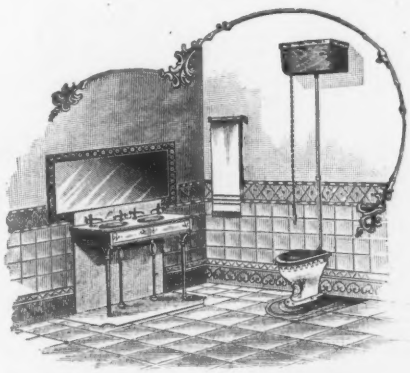

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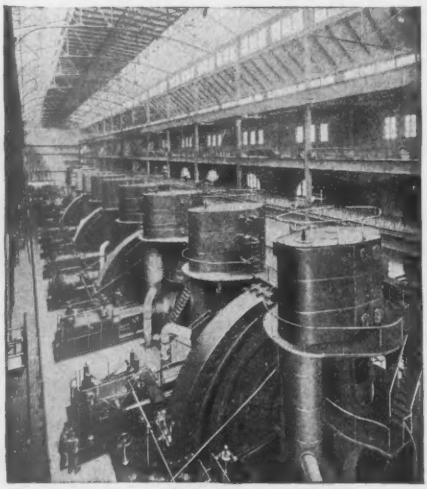

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